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Corrigendum

On page 113 of the most recent issue of *The Victorian Naturalist* (volume 136, no. 3) the date of collection of one of the six paralectotypes at a site in Donvale was mistakenly given as '1980'. The date should have been '1890'. The Editors apologise for any confusion caused by this error.

The Victorian Naturalist

Volume 136 (4) 2019 August

Editors: Gary Presland, Maria Gibson, Sue Forster

Editorial Assistant: Virgil Hubregtse

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Front cover: Little Whip Snake *Parasuta flagellum*. Photo Grant Turner (see p. 128)

Notes on the natural history of the Little Whip Snake *Parasuta flagellum* (Elapidae) from basalt plains grasslands near Melbourne

Grant S Turner

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Abstract

Three populations of the Little Whip Snake *Parasuta flagellum* inhabiting remnant grasslands to the north and west of Melbourne were examined. Most snakes (79%) were located by day from April–October when inactive beneath surface stones resting either directly on soil or on other stones. During this period, feeding and growth were minimal and no mortality was recorded. During the active season (November–March), significantly fewer snakes were located beneath stones compared to the rest of the year; instead they occupied soil cracks and cavities by day. The size structure of the three populations was bimodal, with adults most abundant (51–61%), followed by juveniles (22–36%); sub-adults were uncommon throughout the year. The three populations were very similar in almost all measures. The sex ratio in each population and in each size class was unity (1:1). Body size did not differ significantly between adult males and females, however, males had significantly longer tails than females in all sizes. Parturition (the act of giving birth) occurred from late January through to mid-April, and sexual maturity was likely attained by the onset of the second winter. The snakes fed mainly, if not exclusively, on small skinks. Sloughing occurred typically twice per year in adults and at least three times per year in immature snakes during the active season. Sources of mortality included grass fires. (*The Victorian Naturalist* **136** (4), 2019, 128–142)

Keywords: *Parasuta flagellum*, grasslands, size classes, sex ratio, snout-to-vent-length

Introduction

The Little Whip Snake *Parasuta flagellum* is a small (max. total length 0.45 m) nocturnal elapid snake that occurs in the south-eastern corners of both New South Wales (NSW) and South Australia (SA) and much of central and south-western Victoria (Wilson and Knowles 1988; Cogger 2014). It occurs in a variety of habitats including dry sclerophyll forest open woodland, grassland and open heath where surface stones or rocky outcrops occur (Jenkins and Bartell 1980; Wilson and Knowles 1988; Ehmann 1992; Cogger 2014; Robertson and Coventry 2019). It is a live-bearer, producing between one and seven young in late summer or early autumn, and feeds exclusively on small skinks (Fyfe and Booth 1984; Shine 1988; Turner 1989).

Parasuta flagellum is a very common inhabitant of the basalt plains grasslands and grassy woodlands to the north and west of Melbourne (Rawlinson 1965; James 1979). It is the only snake species originally described from the Melbourne region, with the eight specimens that formed the basis of the description being from the eastern and south-eastern suburbs and the Mornington Peninsula (McCoy 1878).

Populations of *P. flagellum* from three remnant native grasslands near Melbourne were examined to determine the size of individuals, the degree of sexual-size dimorphism, the occurrence of size classes, sex ratio, activity, the timing of reproduction, habitat use and diet.

Methods

Sites

A survey of three disjunct populations of *P. flagellum* situated north and west of Melbourne at Deer Park (37° 46' S, 144° 46' E), Somerton (37° 38' S, 144° 58' E) and Bundoora (37° 42' S, 145° 03' E) was conducted during the period 1990–94 inclusive. These sites are situated on the Werribee–Keilor plains, an extensive and geologically recent series of lava flows (<2 mya; Cochrane *et al.* 1991). The plain is deeply dissected by creeks that have exposed layers of sub-surface basalt, and weathering has exposed extensive areas of surface basalt stones and exfoliations. The soil is mainly heavy clay which undergoes extensive seasonal swelling and contraction. Stony rises occur, particularly in the north, and have shallow friable loam soils with numerous surface exfoliations and larger imbedded basalt stones. Each of the sites consisted of naturally occurring remnant grassland with

stands of Kangaroo Grass *Themeda triandra*, numerous small ground herbs and sparsely distributed trees and/or shrubs.

(i) Deer Park (West), 17 km west of the Melbourne CBD (50 m asl; annual rainfall 535 mm: Laverton RAAF weather station (WS), BOM 2017): approximately 250 ha bounded by Robinsons Road, Ballarat Road, Kororoit Creek and farmland. The site was mostly flat except for land sloping steeply down to the creek. Vegetation consisted of treeless *T. triandra* dominated grassland with sparsely occurring Tree Violet *Melicytus dentatus* (<2 m in height) and Dwarf Tree Violet (*M.* sp. aff. *dentatus*) that grew mainly along dry-stone walls and escarpment lining the creek. Soil consisted predominantly of red clay-loam duplex. Outcropping basalt on the flats was also extensive and fairly evenly spread, though some surface stone had evidently been gathered in the construction of dry-stone walls. The suburbs of Burnside and Caroline Springs now occupy this site.

(ii) Somerton, 21 km north of the Melbourne CBD (179 m asl; annual rainfall 610 mm: Greenvale WS, BOM 2017): approximately 100 ha bounded by the Craigieburn Grassland Nature Conservation Reserve, Merri Creek, a basalt quarry and farmland. The site was gently undulating with stony rises supporting small stands of Black Wattle *Acacia mearnsii*, Blackwood *Acacia melanoxylon*, Hedge Wattle *Acacia paradoxa*, Sweet Bursaria *Bursaria spinosa* and Drooping Sheoak *Allocasuarina verticillata*. Stony rises were interspersed by *T. triandra* dominated flats with scattered River Red Gum *Eucalyptus camaldulensis*. Soil consisted of black Mooleric and Grenville clays with Corangamite stony loam soils occurring around escarpment and stony rises. Substantial parts of the site have now been modified by quarrying and grazing.

(iii) Bundoora, 16 km north-east of the Melbourne CBD (83 m asl; annual rainfall 673 mm: LaTrobe University WS, BOM 2017): approximately 80 ha bounded by McKimmies, Dalton and Plenty Roads, extending to just south of the Northern Ring Road. The site comprised a wetland, adjoining sloping ground with abundant surface stones, with the Darebin Creek separating a small area of stony rise. Vegetation consisted of open stands of mature *E. camaldulensis* along with *A. mearnsii*, *A. melanoxylon* and *B. spinosa*, with a grassy understorey consisting mainly of *T. triandra* and Common Tussock Grass *Poa labillardieri* and a variety of exotic grasses, herbs and shrubs, including a dense stand of Gorse *Ulex europaeus* and Cape Broom *Genista monspessulana* on slopes and also covering nearly all of the stony rise. Escarpment occurred along only a small section of the Darebin Creek. Soils consisted of black Mooleric and Grenville clays with Corangamite stony loam soils occurring around escarpment and stony rises. Parts of this site remain, though are much degraded by the encroachment of light industry, residential housing, and the Northern Ring Road.

Searches

Over the five years of this study, searches for snakes occurred in all months of the year with approximately equal effort as measured by the total hours spent searching. The aim of each search was to locate all *P. flagellum* within a given area at a site. All areas at each site were searched once during the same year and each site was searched at least twice over the five years. Recaptured individuals were not included in the analyses. Snakes were located during daylight hours by: (i) lifting ground cover (mainly basalt stones) by hand and carefully replacing it and, (ii) by inspecting soil cracks and large crevices in basalt exfoliations with a torch light. Night searches for snakes that were active away from ground cover were conducted in all months of year to establish when the species was active, however, snakes were more difficult to locate than by day because of the dense grassy ground layer. Snakes located during night searches were neither processed (see below) nor included in any of the quantitative analyses.

Measurements and examination of snakes

For each snake captured the following details were recorded: snout-to-vent length (SVL), measured from the tip of rostral scale to the posterior edge of the anal scale, and tail length (TL), measured from the posterior edge of the anal scale to the tail tip. Snakes were held out-

stretched against a rigid wood-laminate ruler with 1 mm gradations. For SVL measurements the snakes were held behind the head and midway along the tail, while for TL measurements the tail was held close to the tail tip and also just above the vent. SVL and TL measurements were recorded only when snakes had 'relaxed' sufficiently (i.e. body contractions had ceased). Obtaining reliable SVL measurements of live snakes can be difficult (see Blouin-Demers 2003) and so SVL was measured a second and, occasionally, a third time until a consistent measurement was obtained. Head length (HL) was measured from the tip of the rostral scale to the extremal point of contact of the two parietal scales along the midline using a vernier caliper accurate to 0.02 mm. Mass was measured using a spring balance accurate to 0.01 g; gravid females were excluded from all statistical analyses involving mass. HL and mass were measured in only 25% of all snakes processed. Sex was determined by visual inspection of the tail, the species being sexually dimorphic from birth in both tail shape and length (see Rawlinson 1965; Turner 1992, 1999). Snakes were deemed to be sexually mature if in males SVL ≥205 mm and females SVL ≥230 mm based on Shine's (1988) dissections of Victorian and NSW specimens. It was useful to delineate the following size classes: adult (A) consisting of sexually mature snakes with SVL >240 mm, sub-adult (S) consisting of both sexually mature and immature snakes with SVLs between 180 mm and 240 mm (inclusive), and juvenile (J) with SVL <180 mm. Neonates were identified by their small size and the presence of a conspicuous umbilical scar. Each snake's general condition, whether they were pre or post-slough, the presence of scars, injuries and scale abnormalities (along with the nature and location of abnormalities) was recorded. A sketch was made of the overlap pattern of the imbricate head scales and the distribution of black pigment on the head scales and the snout; these characteristics were sufficient to permit the identification of individual snakes (pers. obs., 1991; see also Ferner 2007). Snakes were also palpated for the presence of food boli and oocytes/embryos. The ventral region close to the vent was examined for the presence of faecal and uric acid masses that were sometimes visible through the translucent ventral surface, particularly in juveniles. Faecal samples and regurgitated food items were collected opportunistically when snakes expelled them during processing, and faecal samples were later dried before being examined. Some snakes escaped before or during processing and the information obtained from these specimens, though incomplete, was included. For a subset of snakes captured, the surface temperature beneath their refuge and surface (shade) temperature of adjacent exposed ground were recorded using a digital thermometer with a probe (±)0.1 °C).

Data analyses

Normal probability plots of all body size variables were examined to assess the normality of data. In addition, the Shapiro-Wilk and the D'Agostino-Pearson K^2 test were used to detect departures from normality. When size classes were pooled, data sets of all body size variables were not normally distributed (even when transformed) due to the presence of two distinct size classes (see below); analysis of these pooled data sets was therefore limited to non-parametric methods. Partitioning body size data into juvenile and adult size classes resulted in normally distributed data sets, which were analysed using parametric statistics. A scatter plot of pairs of body size variables was used to determine the type of relationship (i.e., linear, non-linear or none) existing between them. For non-linear relationships, transformations were applied to one or both variables until a strongly linear plot was produced. The Kendall tau (τ) statistic was used to measure the strength of linear relationship between body size variables. Theil-Sen (non-parametric) linear regression was employed to determine equations relating body size variables; ordinary least squares (OLS, parametric) linear regression were computed for comparison. Student's *t*-test (or modified *t*-test) was used to compare means, slopes and intercepts of regression lines and the Mann-Whitney U-test was used to compare means of non-parametric data sets. Comparison of the mean values of body size variables between sexes in adults was performed using ANCOVA (with SVL as the covariate). The χ^2 statistic was used to test deviations from expected frequencies in both one- and two-way classifications and the correction for continuity

used where appropriate. The abbreviations s.e. and CI were used for the standard error and confidence interval respectively. Statistical tests were deemed significant at 0.05 probability level. Probabilities resulting from correlations between body size variables were all one-tailed and those resulting from *t*- or U-tests were two-tailed, unless otherwise stated. Analyses were performed using Statistica (V.12), KTRLine (V.1) (Granato 2006; see also Wilcox 2010) and Microsoft Excel.

Results

Average and extreme body sizes

Adult male and female body sizes were similar with no significant difference in the mean SVL (t = 0.445, 228df, P = 0.657; Table 1). The combined mean adult SVL was 282 mm (s.e. 30.7, n = 259). The largest adult male and female had SVLs of 362 mm and 350 mm respectively. Significantly more males than females had SVL ≥ 300 mm (42 vs 23; χ^2 = 4.986, 1df, P = 0.025). The largest HL (12.64 mm) was from an adult male; the same specimen also had the largest SVL (362 mm) and equal largest TL (68 mm). The heaviest snake, a gravid female (SVL 300 mm, TL 40 mm), weighed 35.5 g and was located in late January. The heaviest non-gravid female weighed 28.1 g (SVL 335 mm, TL 47 mm) while the heaviest male weighed 32.7 g (SVL 342 mm, TL 68 mm). The smallest juvenile recorded was a male with SVL 110 mm while the smallest juvenile female had a SVL of 114 mm; both fall within the SVL range recorded for neonate *P. flagellum* (Turner 1985 and unpublished data 1994). A male neonate with SVL 113 mm had both the smallest HL (7.20 mm) and smallest mass (1.76 g).

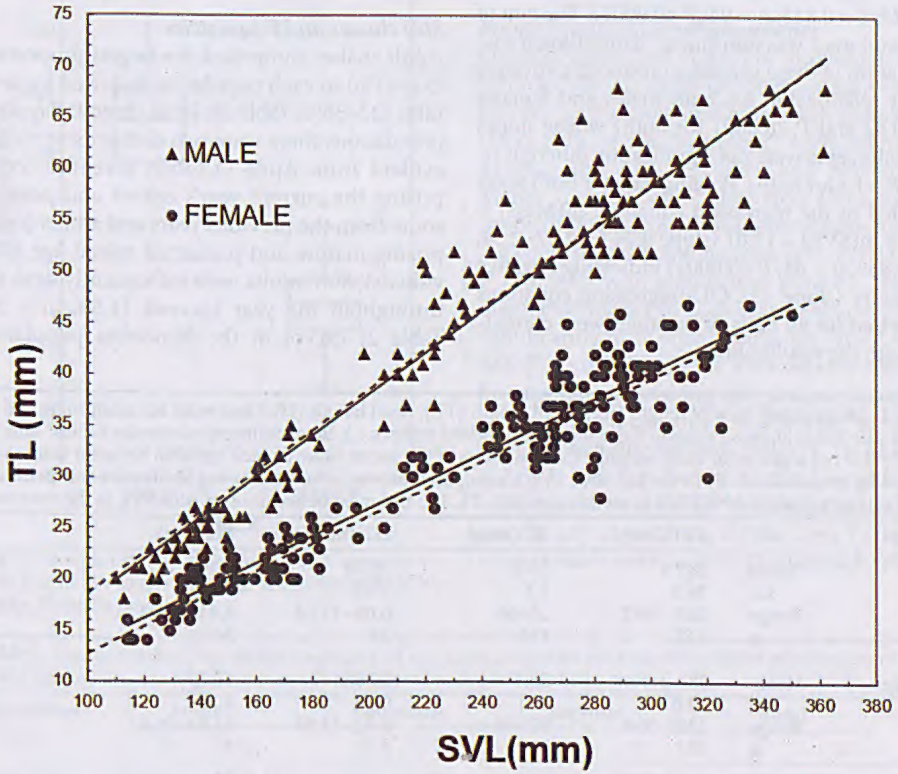

Fig. 1. Plot of tail length (TL) versus snout-to-vent length (SVL) for all Little Whip Snakes *Parasuta flagellum*. Broken lines represent Theil-Sen regression lines and solid lines represent OLS regression lines, drawn for each sex. Triangles represent males (n = 190); circles represent females (n = 210).

Relationship between body size variables

SVL was strongly correlated with all other body size variables in *P. flagellum* of all sizes. There was a highly significant positive correlation between SVL and TL in each sex: male $\tau = 0.780$, n = 190 and female $\tau = 0.774$, n = 210; both $P < 0.0001$ (Fig. 1). Linear regression equations were: males TL = 0.200 × SVL – 1.400 (slope 95% CI 0.193–0.208); and females: TL = 0.135 × SVL – 0.780 (slope 95% CI 0.130–0.141). The slopes and intercepts for these regression equations were significantly different (slopes: $t = 13.8$, 396df, $P < 0.0001$; intercepts: $t = 34.2$, 397df, $P << 0.0001$). There was a highly significant positive correlation between SVL and HL in each sex ($\tau > 0.83$ and $P < 0.0001$ for both) and the slopes and intercepts of the regression equations were not significantly different (*t*-test; $P > 0.2$ for both). Pooling data resulted in the regression equation: HL = 0.0213 × SVL + 4.51 (slope 95% CI 0.0202–0.0223; $\tau = 0.843$; n = 94; $P < 0.0001$). The plot of SVL and mass was non-linear; natural-log transformation of these variables produced a strongly linear relationship for both males and females ($\tau > 0.82$ and $P < 0.0001$ for both) whose slopes and intercepts were not significantly different (*t*-test; $P > 0.5$ for both). Pooling data for both sexes resulted in the regression equation: ln(Mass) = 2.46 × ln(SVL) – 11.01 (slope 95% CI 2.37–2.54; $\tau = 0.833$; n = 84, $P < 0.0001$) indicating negative allometry (slope <3). OLS regression equations generated for all pairs of variables were consistent with the results above.

Sexual dimorphism in tail length

When comparing body size variables between adult male and female snakes, SVL was controlled for (since it was highly correlated with all other variables) and the only variable in which a significant difference was found was TL (ANCOVA $F_{1,255} = 1272$, $P < 0.0001$; HL $F_{1,59} = 1.85$, $P = 0.179$; Mass $F_{1,57} = 67.71$, $P = 0.735$; Table 1). Adult males had significantly longer tails than females. Juvenile male and female tail lengths exhibited the same trend ($t = 5.374$, 145df, P (1-tailed) <0.001). The mean ratio of TL to SVL for all males was 0.189 and all females was 0.135 and these were significantly different (Mann-Whitney U = 9.50, n = 210, 190, P (1-tailed) <0.00001). Only one female ratio (an outlier) fell inside the male range (Fig. 2) and therefore the TL/SVL ratio would appear to be reliable means of distinguishing males (ratio >0.16) from females (ratio <0.16).

Size classes and frequencies

Adult snakes comprised the largest proportion (51–61%) in each population followed by juveniles (22–36%; Table 2). In all three *P. flagellum* populations there were two distinct size classes evident from April–October: juveniles (comprising the current year's cohort and possibly some from the previous year) and adults (comprising mature and presumed mixed-age individuals). Sub-adults were infrequently detected throughout the year (overall 11.5%, n = 54; Table 2) except in the Bundoora population

Table 1. Mean snout-to-vent length (SVL), tail length (TL), head length (HL) and mass for adult male and female Little Whip Snakes *Parasuta flagellum*. The standard error (s.e.), the maximum/minimum values* and the sample size (n) is given for each variable. Comparisons of the mean value of each variable between sexes is indicated by probabilities (P) in the last row: SVL is compared between the sexes using Student's t-test (with unequal variances) while ANCOVA is used to compare TL, HL and mass between sexes with SVL as the covariate.

Adult		SVL (mm)	TL (mm)	HL (mm)	Mass (g)
Male	Mean	282.9	55.4	10.58	17.92
	s.e.	36.5	7.1	1.51	3.92
	Range	205*–362	35–68	6.06–12.64	9.41–32.74
	n	135	135	29	36
Female	Mean	281.2	38.1	10.68	18.75
	s.e.	23.0	4.1	0.78	4.36
	Range	230*–350	32–48	8.42–11.88	12.64–29.65
	n	124	123	31	35
	P	**0.657**	**0.000**	**0.179**	**0.735**

* The minimum SVLs for each sex are from data in Shine (1988) for Victoria and New South Wales specimens (combined) at sexual maturity: males 205 mm, females 230 mm.

(17.2%). The Bundoora population had a significantly larger proportion of sub-adults (t = 2.355, 404df, P = 0.019; Table 2) and a significantly smaller proportion of adult snakes with SVL ≥ 300 mm compared to the Deer Park population (t = 2.75, 322df, P = 0.006; Fig. 3).

The existence of two size classes is shown in the monthly distribution of SVLs where a 'gap' in the size structure is evident (Fig. 3). It is also evident in the SVL distribution (Fig. 4), which is clearly bimodal, with the modes corresponding to the juvenile (160–180 mm) and adult (280–300 mm) size classes. There was no significant association between size class frequencies and population (2×3 contingency table: χ^2 = 4.477, 2df, P = 0.107), but there was significant association between the population structure in April-October (A 57.7%, S 8.4%, J 33.9%; n = 369) compared to November–March (A 66.3%, S 18.8%, J 14.9%; n = 101; 3×2 contingency table: χ^2 = 20.535, 2df, P <0.0001). Significantly greater numbers in each size class were encountered during April–October compared with November–March (J: χ^2 = 54.05, 1df, P <<0.0001; S: χ^2 = 5.357, 1df, P = 0.021; A: χ^2 = 33.68, 1df, P <<0.0001). The number of snakes in each size class (totals in Table 2) differed significantly from the uniform distribution of SVLs (generated using SVLs ranging from 100–360 mm, which gives the expected ratio A: S: J = 6: 3: 4; χ^2 = 43.62, 2df, P <<0.0001) and the same was true in each population (Deer Park χ^2 = 34.263, 2df, P <<0.0001; Somerton χ^2 = 6.841, 2df, P = 0.0327; Bundoora χ^2 = 11.276, 2df, P = 0.0036).

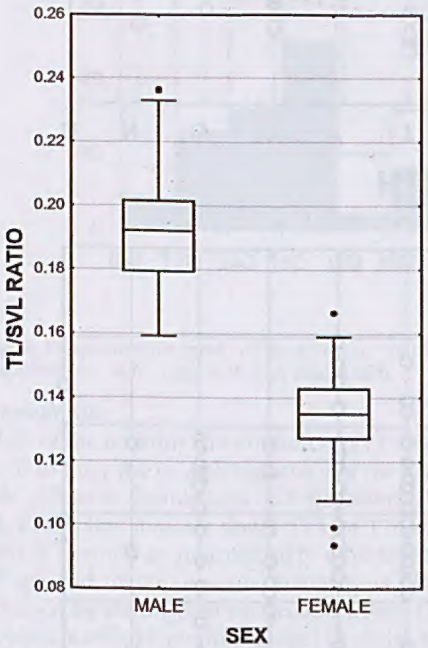

Fig. 2. Boxplot of the tail length (TL) to snout-to-vent length (SVL) ratio for each sex in the Little Whip Snake *Parasuta flagellum*.

Monthly and seasonal abundance

Overall 78.5% (369 of 470) of individuals were recorded during April-October (inclusive), and this proportion was similar for each population (Deer Park 78.5%, Bundoora 73.4%, Somerton 84.8%). The April–October and November–March frequencies of detection were significantly different from those generated by assuming equal monthly frequencies (χ^2 = 121.11, 1df, P <<0.0001 with populations pooled). The frequency of snakes in each season also departed significantly from equal frequency (χ^2 = 130.53, 3df, P <<0.0001). Sexes were equally likely to be encountered during any season except for summer when (gravid) females were more frequently encountered than males (F 29, M 15; χ^2 = 3.843, 1df, P = 0.050). No snakes with SVL <200 mm were recorded in December and January in any population; for the Deer Park population none were recorded in February also.

Table 2. Frequency and percentage frequency of size class categories for each of the three populations of Little Whip Snake *Parasuta flagellum* (n = 470). See text for definition of size classes.

Population	Adult		Sub-adult		Juvenile		Total	
	n	%	n	%	n	%	n	%
Deer Park	144	60.8	19	8.0	74	31.2	237	50.4
Somerton	54	51.4	13	12.4	38	36.2	105	22.3
Bundoora	78	60.9	22	17.2	28	21.9	128	27.2
Total	**276**	**58.7**	**54**	**11.5**	**140**	**29.8**	**470**	**100**

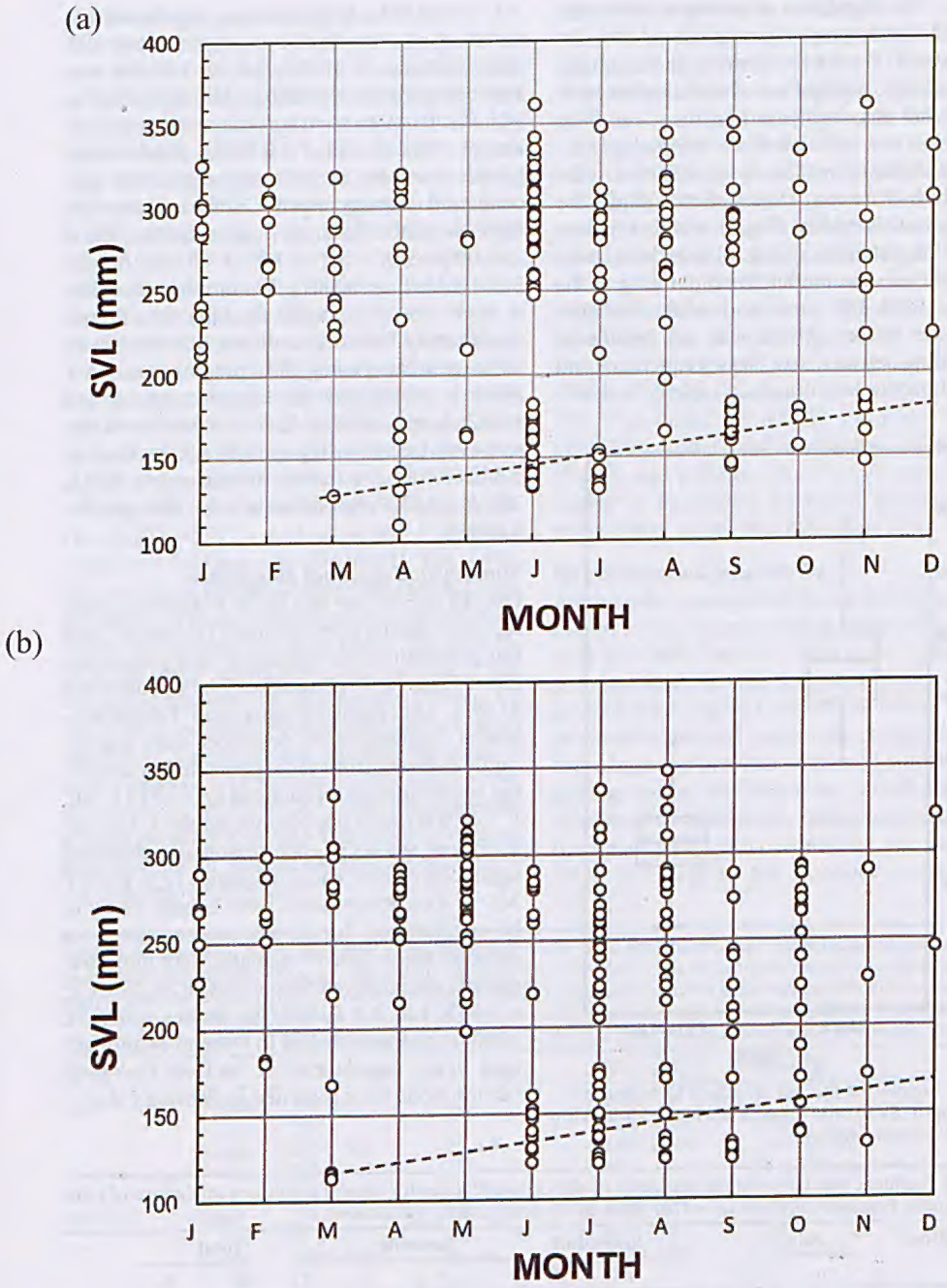

Fig. 3. Plot of the monthly occurrence of snout-to-vent length (SVL) in (a) the Deer Park population and (b) the Bundoora and Somerton populations of Little Whip Snakes *Parasuta flagellum*. The dashed line indicates the inferred growth rate of the juvenile size class.

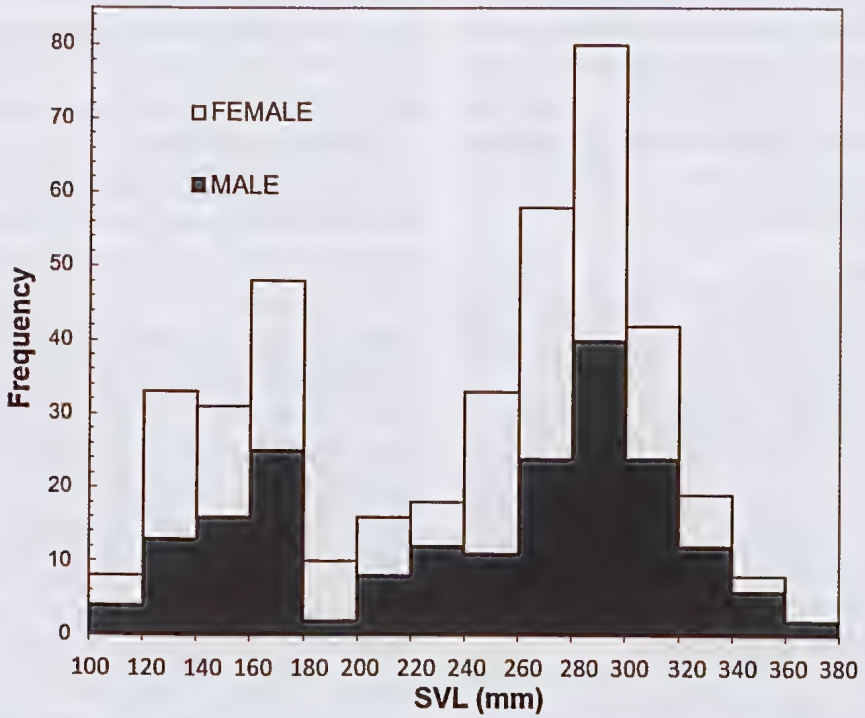

Fig. 4. Frequency histogram of the snout-to-vent length (SVL) distribution of the Little Whip Snake *Parasuta flagellum* (n = 406) using a 20 mm class width.

Growth rate

Plots of the monthly distribution of SVLs were used to infer the growth trajectory of the juvenile cohort in populations of *P. flagellum* (Fig. 3). Both plots indicate that a SVL of 170–180 mm is attained at approximately nine months of age and therefore sexual maturity is likely attained by the onset of the second winter (i.e. approximately 14 months of age) in males but perhaps later in females due to the larger SVL at which they attain maturity. Repeated SVL measurements of 17 adults and 22 juveniles during the period April–October indicated that growth does occur but is minimal (SVL difference <5 mm).

Timing of reproduction

All juveniles with SVL <120 mm were recorded in March and one in April (n = 8; this includes all neonates), corresponding to the known parturition time for the species around Melbourne (Turner 1989; but see Fyfe and Booth 1984). Gravid females were recorded from December through to April (n = 23), with most recorded in February (n = 12). Only one gravid female was found in (early) April. Post-parturient females were recorded in February (n = 1) and March (n = 9), again indicating that parturition occurs mainly in these months. One female recorded in mid-July still had a conspicuous lateral skin fold indicating recent parturition or limited feeding since parturition. The smallest juveniles recorded in winter had SVL 120 mm (n = 3) and, while this falls within the range of neonatal sizes (G Turner, unpublished data, 1996), there was no indication of recent birth (all were found singly and had sloughed since birth).

Sex ratio

The frequency of each sex in adult, sub-adult and juvenile size classes is shown in Table 3. The sex ratio did not differ significantly from

unity (1:1) in each size class (populations pooled: A: $\chi^2 = 0.015$, 1df, $P = 0.902$; S: $\chi^2 = 0.018$, 1df, $P = 0.892$; J: $\chi^2 = 0.122$, 1df, $P = 0.727$) nor in each population (size classes pooled: Deer Park $\chi^2 = 0.192$, 1df, $P = 0.661$; Somerton $\chi^2 = 0.148$, 1df, $P = 0.700$, Bundoora $\chi^2 = 0.451$, 1df, $P = 0.502$). Furthermore, the sex ratio within each size class of each population was also unity (all $P > 0.1$). Pooled over both size class and population the ratio was 1.006 (M/F).

Activity

Nocturnal activity away from refugia was recorded in the months October through to April (inclusive) with most occurrences during the period November–March (89%; n = 55). This suggests very limited or no nocturnal activity in the months of October and April. Nocturnal activity was not recorded from May to September inclusive. Most individuals observed to be active were adults (78%), with only three juveniles seen (5%); it is likely their smaller size and the dense ground cover accounted for this small number.

Habitat use and preferences

In all months of the year snakes were located beneath basalt stones resting either directly on soil (66%) or on other stones (i.e. exfoliations, 19%) on both flat or sloping ground in well-drained areas. Of those snakes located directly on soil, most were located on clay soil (78%) as opposed to loam soil (22%). Both of these differences reflect the more limited occurrence of stony rise habitat where both exfoliations and loam soil occurred compared to the widespread and abundant surface stone resting on clay at each of the sites (see comments below). Some snakes were found beneath stones that had been recently disturbed or over-turned and were resting on dry grass beneath rather than directly on soil (n = 16). Those snakes that were not located beneath stones were either: (i) at the edge of stones or crevices basking while partially concealed (3%; see Turner 2001), (ii) in the open away from stones basking and/or inactive (n = 4, <1%) or, (iii) beneath artificial debris (e.g., vinyl, wooden fence posts, cardboard, concrete, corrugated iron and carpet; n = 31, 7%). The soil substrate on which snakes were found was generally moist but varied from saturated (n = 6; 1%) to dry and friable (n = 37; 8%). Only eight snakes were located in burrows beneath stones on loam soil (see Turner 2014). During the cooler months, basalt exfoliations were almost always occupied by *P. flagellum*. Significantly fewer *P. flagellum* were located beneath surface stones and surface debris from November–March compared to the rest of the year (99 vs 367, $\chi^2 = 71.18$, 1df, $P << 0.0001$). Stones that were occupied by snakes during the cooler months were nearly all unoccupied during the summer months (n >250). During summer and early autumn *P. flagellum* were observed occupying cracks and crevices that had formed in clay soil both beneath stones and also at the edge of deep crevices in basalt exfoliations by day ($n \approx 40$). The drying clay and clay loam soils at the three sites had undergone significant contraction, producing deep cracks (>1 m) resulting in a labyrinthine structure of the sub-soil that provided refuges for *P. flagellum* (as well as other reptiles and invertebrates; pers. obs.). Three adult *P. flagellum* were seen at depths exceeding 0.4 m; seven other adults were seen at shallower depths, and eight snakes, including both adults and sub-adults, were observed to quickly retreat down soil cracks when stones were lifted on warm summer days. The temperature beneath stones where *P. flagellum* were located was in nearly all instances less than (or equal to) either air temperature or the temperature at ground level beside the stone. The mean surface temperature beneath stones was 16.3 °C (range 7.4–31.3

Table 3. Frequency of each sex in adult, sub-adult, and juvenile Little Whip Snakes *Parasuta flagellum* (n = 470). Sex was undetermined in ten individuals due to incomplete data collection.

Sex	Adult		Sub-adult		Juvenile		Total	
	n	%	n	%	n	%	n	%
Male	134	48.5	28	51.9	63	45.0	225	47.9
Female	141	51.1	26	48.1	68	48.6	235	50.0
Unknown	1	0.4	0.0	0.0	9	6.4	10	2.1

°C; n = 89). The median surface temperature difference between refuges and adjacent exposed ground was 4.4 °C (range: −2–28 °C; n = 77) with the largest temperature differences recorded in summer. Daytime maximum temperatures in summer beneath a sample of stones (n = 20) occupied by *P. flagellum* the previous winter were routinely found to exceed 40 °C on days when shade temperatures did not exceed 32 °C. Prolonged exposure to such high temperatures would be lethal to *P. flagellum* (see Discussion).

Diet and feeding

Examination of faecal material (n = 41) and regurgitated food items (n = 22) indicated that *P. flagellum* of all sizes fed on small skinks. Faecal samples were all found to contain numerous skink scales. The Garden Skink *Lampropholis guichenoti* and the Tussock Skink *Pseudemoia pagenstecheri* were the only identifiable regurgitated items, and all scales in faecal samples were consistent in size and profile with these two species. These skinks were abundant at the three sites (though *L. guichenoti* was uncommon except at the Bundoora site). Insect remains (including beetle elytra, dipteran wings) were present in some faecal samples (n = 5) but were presumed to have been secondarily ingested, being either consumed by skinks or else had adhered to skinks during ingestion (as was observed in several regurgitated samples). Black Field Crickets *Teleogryllus commodus* were readily available potential prey for *P. flagellum* given their size, abundance in summer/autumn, and their occurrence beneath stones occupied by *P. flagellum* (see below) but their remains were never found in faecal samples. The samples therefore indicate that all three populations of *P. flagellum* fed primarily, if not exclusively, on skinks. Regurgitated or palpated prey and faecal masses (either expelled or visible through the ventral scales) were recorded only during the months spanning September through to May (n ≈ 60), indicating that feeding ceases or is infrequent outside this period.

Cohabitation

Parasuta flagellum was often found beneath stones also occupied by most other reptile and frog species that inhabited the grasslands (15 spp.; Table 4), including known prey species, though they were rarely in direct body contact with any. They were most often found together and in direct body contact with conspecific adults and/or juveniles—these aggregations

Table 4. List of vertebrates and invertebrates found cohabiting with Little Whip Snakes *Parasuta flagellum* beneath refuges.

Vertebrates	Invertebrates
Frogs	Flatworms (Platyhelminthes)
Ewing's Tree Frog *Litoria ewingii*	*Common Garden Snail *Cornu aspersum*
Eastern Banjo Frog *Limnodynastes dumerilii dumerilii*	*White Italian Snail *Theba pisana*
Spotted Marsh Frog *Limnodynastes tasmaniensis*	*Pill-bug *Armadillidium vulgare*
Sudell's Frog *Neobatrachus sudellae*	Major Flatrock Spider *Morebilus plagusius* (Trochanteriidae)
Common Eastern Froglet *Crinia signifera*	Prowling Spider *Miturga* sp.
Lizards	Black Field Crickets *Teleogryllus commodus*
Marbled Gecko *Christinus marmoratus*	Slugs > 2 sp.
Spalding's Ctenotus *Ctenotus spaldingi*	Darkling Beetle *Adelium similatum*
Striped Legless Lizard *Delma impar*	Ground Beetle *Notonomus gravis* (Carabidae)
Garden Skink *Lampropholis guichenoti*	*Slaters *Porcellio scaber*
Bougainville's Skink *Lerista bougainvillii*	*European Earwig *Forficula auricularia*
Tussock Skink *Pseudomoia pagenstecheri*	*Portuguese Millipede *Ommatoiulus moreleti*
Eastern Blue-tongue Skink *Tiliqua scincoides*	Scolopendrid centipedes 1 sp.
Snakes	Cockroaches (Blattodea) >2 spp.
Lowland Copperhead *Austrelaps superbus*	Ants >3 spp.
Mainland Tiger Snake *Notechis scutatus*	
Eastern Brown Snake *Pseudonaja textilis*	
Mammals	
*House Mouse *Mus musculus*	
Fat-tailed Dunnart *Sminthopsis crassicaudata*	

*Introduced species. The list of Arthropod cohabitants is incomplete and restricted to the larger, more readily indentifiable taxa.

are the subject of a separate publication (Turner, in prep.). Juvenile Eastern Brown Snakes *Pseudonaja textilis* were sometimes found cohabiting with adult *P. flagellum* during winter months (n = 9), which probably reflects their similar size and choice of winter refuges. Apart from conspecifics, direct body contact occurred between *P. flagellum* and: (i) juvenile *P. textilis* (n = 3) and (ii) a juvenile Lowland Copperhead *Austrelaps superbus* (n = 1). Cohabitation occurred with both adults and juveniles of the frog and reptile species listed in Table 4 with the exception of one frog (*L. tasmaniensis*) and a lizard (*C. marmoratus*), where only adults were recorded.

Sloughing frequency

A total of 51 snakes of various sizes were in either pre- or post-slough condition. All were located in the months October–April. Sloughing in adult *P. flagellum* appears to take place twice yearly in November–December (n = 5) and in February–March (n = 24) when snakes are active and feeding. Juveniles and subadults appear also to slough at approximately these times (n = 5; November–December and n = 13; March–April), but some likely have a third slough in between these times (n = 4 sub-adults). Sloughed skin was rarely found (n <20) beneath refuges indicating that sloughing occurs when snakes are active and away from refuges.

Injuries, general condition and sources of mortality

The incidence of injuries in snakes was low, with only 14 affected individuals (3%). Of these, three were males and the remainder females; both adults (n = 10) and juveniles (n = 4) were represented in the sample. The most common types of injury (n = 11) were deep wounds gouged into one side of the mid-posterior flank or tail. The wounds did not seem to hinder the movements of snakes and all were completely healed. They are likely the result of attempted predation. Other injuries included burns (n = 2) and eye damage/blindness (n = 3) that affected only one eye in each instance. The most severe injury observed was numerous lesions resulting from burns on an adult male snake, which were almost certainly the result of a recent grass fire in the area. Unusually this snake was out and fully exposed during the day, basking in midwinter. Four snakes had small infestations of the introduced snake mite *Ophionyssus natricis*. There were no obvious signs of disease affecting any snakes. Nine post-parturient females located in March and April were noticeably underweight but none were seen in this condition during the winter months. Of 22 juveniles and more than 20 adults that were monitored in the field between April–October, all were found to have survived the period of inactivity and they did not exhibit any noticeable deterioration in condition over this time. The remains of only three adult *P. flagellum* were located in the open, two of them apparently victims of grass fires (see also Schultz, 1985), while for the third, the cause of death was not apparent.

Discussion

Studies on the population structure of Australian elapid snakes have tended to focus on the larger species (e.g. Tiger Snakes *Notechis* spp. Schwaner 1985, 1991; Schwaner and Sarre 1988, 1990; Butler *et al.* 2005a, b; Bonnet *et al.* 2002; Red-bellied Black Snakes *Pseudechis porphyriacus* Shine 1987; Eastern Brown Snake *Pseudonaja textilis* Whitaker 2000, 2001; Whitaker and Shine 2003), with only two smaller elapid species, the Broad-headed Snake *Hoplocephalus bungaroides* (Webb and Shine 1997; Webb *et al.* 2002, 2003; Pringle *et al.* 2003) and the Eastern Small-eyed Snake *Cryptophis nigrescens* (Webb *et al.* 2003) being the subject of detailed study. Some of these studies used mark-recapture and/or radiotelemetry to monitor the behaviour and movements of a small number of individuals in a population rather than being a population census, as in this work.

The measures of population structure obtained in this work confirm what is known about *P. flagellum* in relation to individual size and the lack of sexual dimorphism in SVL (see Shine 1988). This latter measure is at odds with most other species in the genus *Parasuta* in which males have larger SVL than females (see Shine 1988) and is also at odds with the occurrence of male-male combat in this species (Turner 1992); this behaviour is typically associated with sexual dimorphism where males are larger than females (Madsen and Shine 1993). The size class structure and sex ratio of *P. fla-*

gellum populations are consistent with those of larger elapids (see Shine 1994; Greer 1997). The lack of a difference in the SVL and mass relationship between males and females is consistent with the data available for most Australian elapid snakes, and, furthermore, the negative allometry detected between these variables occurs also in the only cogener for which data is available (*Parasuta dwyeri*; Greer and Shine 1999).

Limited variation in the measures of population structure across the three *P. flagellum* populations was not unexpected since they likely represent remnants of an historically much larger population that would have occupied grassland habitat extending from the eastern edge of the basalt plains (north-east of Melbourne) through to the south-west coast of Port Phillip Bay. The most notable difference in population structure was in the proportion of the sub-adults, with a more than two-fold difference between the Deer Park and Bundoora populations (8.0% vs 17.2%). These two populations differed markedly in their degree of habitat disturbance, with the Bundoora site having been subject to many years of grazing, leading to much of the native vegetation being replaced by exotic species, and the removal and disturbance of surface stone. In contrast, the Deer Park site was for the most part floristically intact, as was much of the surface stone. Another notable difference was in the dominant prey species at each site, with *Pseudomoia pagenstecheri* being abundant at the Deer Park site but uncommon at the Bundoora site where the smaller *L. guichenoti* was dominant. This difference in abundances of the two prey species, which was reflected in diets of *P. flagellum* at each site, may be due to *L. guichenoti*'s ability to tolerate disturbed grassland habitat (pers. obs., date?). Whether this difference in diet causes variations in growth rate, mean adult size, and the reproductive output of *P. flagellum* populations is not known, but in this work a difference was evident in the maximum adult size.

Sexual dimorphism in tail length and shape in *P. flagellum* has been previously reported (Rawlinson 1965; Fyfe and Booth 1984; Turner 1992), but it had not been quantified. Clarke and How (1995) examined the TL/SVL ratio in the elapid genera *Simoselaps* and *Vermicella* and found that it provided a completely unambiguous means of sexing individual snakes. In *P. flagellum* TL/SVL ratios exceeding 0.16 were exclusively male and those with ratios less than 0.16 female. The ratio may be useful in determining the sex of juvenile snakes that sometimes lack the difference in tail shape that is conspicuous in adult snakes.

The sampling method employed in this work of locating inactive snakes beneath ground cover rather than capturing active snakes (away from cover) is likely to have resulted in unbiased samples with respect to both size and sex. Adults, sub-adults and juveniles all occupied surface stones when inactive during the cooler months and were often found together (Fyfe and Booth 1984; Turner 1989; in prep.). The 1:1 secondary sex ratio for all size classes and populations of *P. flagellum* is consistent with a 1:1 primary sex ratio determined in neonates (G Turner, unpubl. data, 1996). It indicates that the net effect of factors regulating *P. flagellum* populations act in a sexually unbiased way. The 1:1 sex ratio is also consistent with approximately equal numbers of adult males and females determined for other *Parasuta* species (Shine 1988) and other small cryptozoic elapid snakes in museum collections (*Cacophis*, *Cryptophis*, *Denisonia*; Shine 1980, 1983, 1984). The sex ratios of juvenile elapid snakes in the field have been reported in only a few species (see Greer 1997) and, with one exception, were unity. By contrast, the large diurnal elapid snakes represented in museum collections typically exhibit a strong adult male bias (e.g. *Oxyuranus* Shine and Covacevich 1983; *Pseudechis* Shine 1978; *Notechis* Shine 1987; but see Schwaner 1985; Schwaner and Sarre 1988) which Shine (1988) has attributed to collecting bias and the fact that adult male snakes have very extensive movements during the mating season (see below). Large elapids tend to be conspicuous, and thus are most likely to be encountered and hence collected when they are active (by day). By contrast, Schwaner and Sarre (1988) recorded an adult female bias in some populations of the Black Tiger Snake *Notechis ater*, and attributed this to gravid females' propensity to bask in the open. The same explanation has been offered for the female bias in museum specimens of the small diurnal elapid *Drysda-*

lia rhodogaster (Greer 1997; and may perhaps apply also to mainland *D. coronoides*—see data in Shine (1981)) and accounts for a marginally significant female bias recorded in this study during summer when gravid females basked in the open or remained beneath (accessible) ground cover (see Turner 2001).

The comparatively low capture rates of *P. flagellum* during the warmer months of the year when the species is active (November–March) is a pattern consistent with at least two other grassland reptiles. The collection dates of both museum and privately held specimens of the Striped Legless Lizard *Delma impar* from basalt plains grasslands shows that they are much more likely to be collected during the months April–October than the remainder of the year ($\chi^2 = 8.27$, 1df, $P = 0.0038$; frequencies estimated from Figure 7, p. 16 of Coulson 1990). While not quantified, the Pink-tailed Legless Lizard *Aprasia parapulchella* from native grasslands around Canberra is also less frequently encountered during summer (Osborne and McKergow 1993). The same pattern would also be expected to occur in diurnal reptile species which overwinter in refuges that are easily accessed by humans, but when active, are either cryptic and/or difficult to locate. The reason for the low capture rates of *P. flagellum* during the warmer months is their occupancy of soil cracks and crevices probably due to (lethally) high temperatures beneath surface stones at that time of year, with temperatures exceeding the species' known voluntary and critical thermal maxima (VTMax: 34.2–36.2 °C; Lillywhite 1980; CTMax: 39.0–41.0 °C; Spellerberg 1972). This explanation is supported by observations of *P. flagellum* beneath surface stones only early in the morning on summer days when temperatures beneath stones were relatively low, and also on summer days that were unseasonally cool (pers. obs., 1986–1994). It is also possible that *P. flagellum* occupy soil cracks and cavities to avoid dehydration, with the relative humidity of these refuges likely to be much higher than beneath surface stones resting on dry soil.

Two possible, but not mutually exclusive, explanations for the low frequency of sub-adults in *P. flagellum* populations are: (i) high juvenile mortality, and (ii) rapid juvenile growth rates leading to recruitment into the adult size class (i.e., SVL >230 mm) being attained by the onset of the second winter. If high juvenile mortality is responsible for the lack of sub-adults then it must occur largely during the period when the snakes are active since there was no evidence of mortality during the April–October period of inactivity. This explanation would also imply that juvenile mortality was greatest in the Deer Park population where the sub-adult size class was smallest. It may be that, as well as supporting high densities of prey (*P. pagenstecheri*), the Deer Park site also supported high densities of predators compared to the other sites, though evidence is lacking. By contrast, the explanation of rapid juvenile growth is supported by: (i) the growth rates of juveniles in captivity maintained on a natural diet (Turner 1989), (ii) the inferred growth trajectory of the juvenile cohort (Fig. 3), and (iii) by the apparent recruitment of adult snakes (i.e., the appearance of previously unrecorded adult snakes) in each population during this study (pers. obs., 1990–1994).

Finally, as a species *P. flagellum* is ideally suited to demographic studies owing to its abundance in grassland and woodland habitats, its small size that permits easy handling, the visual means (and use of TL/SVL ratio) of determining the sex of individuals of any size, the ease of locating individuals of any size in most months of the year, and the fact that it is not dangerously venomous. A mark-recapture study of this species would be useful in resolving the following questions: (i) whether there are differences between males and females in growth rates, seasonal movements and the extent of these movements, and (ii) whether mortality rates vary significantly between adults and juveniles.

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References

Blouin-Demers G (2003) Precision and accuracy of body-size measurements in a constricting, large-bodied snake (*Elaphe obsoleta*). *Herpetological Review* **34**, 320–323.

BOM (2017) Bureau of Meteorology. <http://www.bom.gov.au/climate/data> Accessed September 2017.

Bonnet X, Pearson D, Ladyman M, Lourdais O and Bradshaw D (2002) 'Heaven' for serpents? A mark-recapture study of Tiger Snakes (*Notechis scutatus*) on Carnac Island,

Western Australia. *Austral Ecology* **27**, 442–450.
Butler H, Malone B and Clemann N (2005a) Activity patterns and habitat preferences of translocated and resident tiger snakes (*Notechis scutatus*) in a suburban landscape. *Wildlife Research* **32**, 157–163.
Butler H, Malone B and Clemann N (2005b) The effects of translocation on the spatial ecology of Tiger snakes (*Notechis scutatus*) in a suburban landscape. *Wildlife Research* **32**(2), 165–171.
Clarke VIR and How RA (1995) Body dimensions in *Simoselaps* and *Vermicella* (Elapidae): a method for determining sex in natural populations. *Records of the Western Australian Museum* **17**, 69–72.
Cochrane GW, Quick GW and Spencer-Jones D (1991) *Introducing Victorian Geology*. (Geological Society of Australia, Victorian Division: Melbourne).
Cogger HG (2014) *Reptiles and Amphibians of Australia*, 7th edn. (Reed: Chatswood, NSW).
Coulson G (1990) Conservation Biology of the Striped Legless Lizard (*Delma impar*)—an initial investigation. Arthur Rylah Institute for Environmental Research Technical Report Series No. 106. Department of Conservation and Environment, Victoria.
Ehmann H (1992) *Encyclopedia of Australian Animals: Reptiles*. (Collins/Angus and Robertson: Sydney).
Ferner JW (2007) *A Review of Marking and Individual Recognition Techniques for Amphibians and Reptiles*. (Society for the Study of Amphibians and Reptiles—Herpetology Circular No. 35: Salt Lake City, Utah).
Fyfe G and Booth P (1984) Some notes on the habits of the Little Whip Snake, *Unechis flagellum*. *Herpetofauna* **16**, 16–21.
Granato GE (2006) *Kendall–Theil Robust Line* (KTRLine, V.1.0): a visual basic program for calculating and graphing robust nonparametric estimates of linear-regression coefficients between two continuous variables. In *Techniques and Methods of the U.S. Geological Survey*, Book 4, Section A Statistical Analysis, Chapter 7. (U.S. Geological Survey: Reston, Virginia).
Greer AE (1997) *Biology and Evolution of Australian Snakes*. (Surrey Beatty & Sons: Chipping Norton, NSW).
Greer AE and Shine R (1999) Relationship between mass and length in Australian elapid snakes. *Memoirs of Queensland Museum* **45**, 375–380.
James G (1979) The Little Whip Snake of the Melbourne area. *Victorian Herpetological Society Newsletter* No.**13**, 11–12.
Jenkins RWG and Bartell RJ (1980) *A Field Guide to the Reptiles of the Australian High Country*. (Inkata Press: Melbourne).
Lillywhite HB (1980) Behavioural thermoregulation in Australian Elapid snakes. *Copeia* **1980**, 452–458.
Madsen T and Shine R (1993) Male mating success and body size in European grass snakes. *Copeia* **1993**, 561–564.
McCoy F (1878) *Hoplocephalus flagellum* (McCoy)—The Little Whip Snake. In *Natural History of Victoria: Prodromus of the Zoology of Victoria 1878-90*, Decade II, pp. 7–8 plus Plate 11. (J Ferres, Government Printer: Melbourne).
Osborne WS and McKergow FVC (1993) Distribution, population density and habitat of the Pink-tailed Legless Lizard *Aprasia parapulchella* in Canberra Nature Park. (Technical Report 3. ACT Parks and Conservation Service: Tuggeranong, ACT).
Pringle RM, Webb JK, and Shine R (2003) Canopy structure, microclimate, and habitat selection by a nocturnal snake, *Hoplocephalus bungaroides*. *Ecology* **84**, 2668–2679.
Rawlinson P (1965) Snakes of the Melbourne area. *The Victorian Naturalist* **81**, 245–254.
Robertson P and Coventry AJ (2019) *Reptiles of Victoria—a guide to identification and ecology*. (CSIRO Publishing: Clayton South, Victoria).
Schultz M (1985) The Little Whip Snake—a victim of wildfire? *Geelong Naturalist* **22**, 35–36.
Schwaner TD (1985) Population structure of the Black Tiger Snakes, *Notechis ater niger*, on offshore islands of South Australia. In *Biology of Australian Frogs and Reptiles*, pp. 35–46. Eds G Grigg, R Shine and H Ehmann. (Royal Zoological Society of NSW/Surrey Beatty & Sons: Chipping Norton, NSW).
Schwaner TD (1991) Spatial patterns in Tiger snakes (*Notechis ater:* Elapidae) on offshore islands of southern Australia. *Journal of Herpetology* **25**, 278–283.
Schwaner TD and Sarre SD (1988) Body size of Tiger Snakes in southern Australia, with particular reference to *Notechis ater serventyi* (Elapidae) on Chappell Island. *Journal of Herpetology* **22**, 24–33.
Schwaner TD and Sarre SD (1990) Body size and sexual dimorphism in mainland and island Tiger Snakes. *Journal of Herpetology* **24**, 320–322.
Shine R (1978) Growth rates and sexual maturation in six species of Australian Elapid snakes. *Herpetologica* **34**, 73–79.
Shine R (1980) Comparative ecology of three Australian snake species of the genus *Cacophis* (Serpentes: Elapidae). *Copeia* **1980**, 831–838.
Shine R (1981) Venomous snakes in cold climate: ecology of the Australian genus *Drysdalia* (Serpentes: Elapidae). *Copeia* **1981**, 14–25.
Shine R (1983) Food habits and reproductive biology of Australian elapid snakes of the genus *Denisonia*. *Journal of Herpetology* **17**, 171–175.
Shine R (1984) Reproductive biology and food habits of the Australian elapid snakes of the genus *Cryptophis*. *Journal of Herpetology* **18**, 33–39.
Shine R (1987) Intraspecific variation in thermoregulation, movements and habitat use by Australian blacksnakes, *Pseudechis porphyriacus* (Elapidae). *Journal of Herpetology* **21**, 165–177.
Shine R (1988) Food habits and reproductive biology of the small Australian snakes of the genera *Unechis* and *Suta* (Elapidae). *Journal of Herpetology* **22**, 307–315.
Shine R (1994) Allometric patterns in the ecology of Australian snakes. *Copeia* **1994**, 851–867.
Shine R and Covacevich J (1983) Ecology of highly venomous snakes: the Australian genus *Oxyuranus* (Elapidae). *Journal of Herpetology* **17**, 60–69.
Spellerberg IF (1972) Temperature tolerances of southeast Australian reptiles examined in relation to reptile thermoregulatory behavior and distribution. *Oecologia* **9**, 23–46.
Turner G (1985) Captive breeding of *Unechis flagellum*. *Herpetofauna* **16**, 53–54.
Turner G (1989) Observations of *Unechis flagellum* (Elapidae). *Herpetofauna* **19**, 1–7.
Turner G (1992) Courtship behaviour and male combat in the Little Whip Snake *Rhinoplocephalus flagellum* (Elapidae). *Herpetofauna* **22**, 14–21.
Turner G (1999) A novel method of identifying sex in neonate Little Whip Snakes *Suta flagellum* (Elapidae). *Herpetofauna* **29**, 10–12.
Turner G (2001) Aggregations and basking in gravid female Little Whip Snakes *Suta flagellum* (Elapidae). *Herpetofauna* **31**, 37–47.
Turner GS (2014) Burrow-use in herpetofauna of the Werribee–Keilor plains. *The Victorian Naturalist* **131**, 72–83.
Turner GS (in prep.) An analysis of aggregations in the Little Whip Snake *Parasuta flagellum* (Elapidae).
Webb JK, Brook BW and Shine R (2002) What makes a species vulnerable to extinction? Comparative life-history traits of two sympatric snakes. *Ecological Research* **17**, 59–67.
Webb JK, Brook BW and Shine R (2003) Does foraging mode influence life history traits? A comparative study of growth, maturation and survival of two species of sympatric snakes from south-eastern Australia. *Austral Ecology* **28**, 601–610.

Webb JK and Shine R (1997) A field study of the spatial ecology and movements of a threatened snake species, *Hoplocephalus bungaroides*. *Biological Conservation* **82**, 203–217.
Whitaker PB (2000) Sources of mortality of large elapid snakes in an agricultural landscape. *Journal of Herpetology* **34**, 121–128.
Whitaker PB (2001) Thermal biology and activity patterns of the Eastern Brownsnake (*Pseudonaja textilis*): a radiotelemetric study. *Herpetologica* **58**, 436–452.
Whitaker PB and Shine R (2003) A radiotelemetric study of movements and shelter-site selection by free-ranging Brownsnakes (*Pseudonaja textilis*: Elapidae). *Herpetological Monographs* **17**, 130–144.
Wilcox RR (2010) *Fundamentals of Modern Statistical Methods*, 2nd edn. (Springer: New York).
Wilson SK and Knowles DG (1988) *Australia's Reptiles—a Photographic Reference to the Terrestrial Reptiles of Australia*. (Collins: Sydney)

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Fire and waterlogging tolerance of Southern Mahogany *Eucalyptus botryoides* Sm. seedlings

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Abstract
In grasslands and woodlands of south-eastern Australia, encroachment by native shrubs has been reported, yet few examples of tree encroachment exist. Recently, Southern Mahogany *Eucalyptus botryoides* (Myrtaceae) has been found encroaching into coastal wet heathland at Cape Conran, Victoria. It has been hypothesised that encroachment was facilitated by a long-term drought reducing the water table depth, an uncharacteristic absence of fire, or an interaction between these two processes. This study aimed to determine the ability of *E. botryoides* seedlings to tolerate waterlogging and fire. Seedling survival was largely unaffected after eight weeks of waterlogging; complete inundation, however, resulted in high mortality (75%). As waterlogging severity increased, growth inhibition became more pronounced. *Eucalyptus botryoides* seedlings had almost complete mortality after being burnt. These findings support the proposed explanation that *E. botryoides* encroachment into a coastal wet heathland is facilitated by the absence of fire and inundation. (*The Victorian Naturalist* **136** (4), 2019, 142–149)

Keywords: coastal wet heathland, woody plant encroachment, vegetation dynamics

Introduction

Encroachment of native woody plants into natural ecosystems is a major concern in many parts of the world (Lunt *et al.* 2010; Archer *et al.* 2017), including south-eastern Australia (e.g. Lunt 1998; Price and Morgan 2008; Lunt *et al.* 2010). The increased dominance of woody plants in natural ecosystems results in the thickening and homogenisation of vegetation, which may have substantial negative impacts on native biodiversity (Lunt 1998; Costello *et al.* 2000; Price and Morgan 2008; Lunt *et al.* 2010; Alofs and Fowler 2013). It is therefore critical to understand the causes and effects of encroachment in natural ecosystems.

Globally, encroachment by woody species has received most attention in semi-arid rangelands where heavy and selective grazing on grasses promotes woody species (Schlesinger *et al.* 1990; Scholes and Archer 1997; Asner *et al.* 2004). Altered fire or other disturbance regimes, changes to soil properties, or a combination of these processes have also been identified as key drivers of woody encroachment (Bowman 2000; Higgins *et al.* 2000; Brook and Bowman 2006; Archer *et al.* 2017).

The coastal grasslands, woodlands and heathlands of south-eastern Australia appear especially susceptible to woody plant encroachment. The range expansion of Coast Tea Tree *Leptospermum laevigatum* (Myrtaceae) is an example of particular concern because of the species' ability to establish in, and then dominate, native ecosystems (Hazard and Parsons 1977; Burrell 1981; Bennett 1994). This consequently

has negative impacts on diversity (O'Loughlin *et al.* 2015) and structure (Morgan *et al.* 2018). In this instance, shrub encroachment has been thought to occur because a lack of fire allows fire-sensitive obligate seeders to establish (Bennett 1994). This is coupled with altered ground-layer competition due to changes in herbivore numbers, further promoting seedling recruitment opportunities for obligate-seeding woody shrubs (Bennett 1994).

Recently, the forest tree *Eucalyptus botryoides* (Myrtaceae) has been reported to have encroached into a coastal wet heathland at Cape Conran, Victoria (Scicluna *et al.* 2018). This finding is unusual as it represents one of the very few cases of a tree species encroaching into heathland. Scicluna *et al.* (2018) hypothesised that encroachment, which had been ongoing since the 1980s, resulted from changes to local hydrology (lowering of the water table because of road construction, coupled with long-term drought) and fire regimes (declines in historic, frequent burning that may have contributed to the maintenance of heathland structure). Coastal heathlands of south-eastern Australia have been found to transition into woodland in the long-term absence of fire (Freestone *et al.* 2015), while flooding tends to limit tree recruitment and survival (Kozlowski 1997; Bailey-Serres and Voesenek 2008). Given this, it is plausible that the absence of fire and the drier conditions experienced have facilitated *E. botryoides* encroachment into the coastal wet heathland.

While mature *E. botryoides* plants possess adaptations to both flooding and fire (Lacey *et al.* 1982; Lacey 1983; Grant *et al.* 1997), the sensitivity of seedlings is unknown. Given recruitment is crucial for range expansion into new habitats, the sensitivity of seedlings to waterlogging and fire was explored in this study to help interpret the changes observed at Cape Conran.

It was hypothesised that *E. botryoides* seedlings would have higher mortality under flooded conditions than non-waterlogged conditions. In addition, it was expected that resource allocation to shoots and roots would change over time under flooding conditions, as roots often decay and overall growth is suppressed during waterlogging (Kozlowski 1997). It was also hypothesised that *E. botryoides* seedlings would be unable to recover from fire. Although lignotubers develop in young seedlings, it was suspected that they would have minimal (if any) functional capacity.

Materials and Methods

Study species

Eucalyptus botryoides (Myrtaceae) is indigenous to the coast of south-eastern Australia where it often occurs on sandy, well-drained and nutrient-poor soils (Lacey 1983; Benson and McDougall 1998; Costermans 2006). It has short-distance seed dispersal, up to 20 m from the parent tree (Benson and McDougall 1998). Mature *E. botryoides* plants possess adaptations to both fire and flood. Despite occurring in relatively high rainfall zones (>700 mm per annum), *E. botryoides* exhibits a dimorphism, allowing it to grow as a mallee form or a forest form depending on environmental conditions (Lacey 1983). When occurring in more stressful environments, *E. botryoides* develops a large lignotuber (Lacey 1983), resulting in the species displaying a relatively high tolerance to fire (Grant *et al.* 1997). Adult plants also have the capacity to reproduce vegetatively by forming roots from fallen branches and stems (Lacey *et al.* 1982). This adaptation is thought to be related to flooding and/or nutrient-poor soils (Lacey *et al.* 1982).

Experimental material

Eucalyptus botryoides seedlings were sourced from the La Trobe University Wildlife Sanctuary. In August 2017, 100 seedlings (no taller than approximately 20 cm) were transplanted from the field to 1 L pots containing a 50% sand, 50% compost-soil mixture. Seedlings were placed in an unheated glasshouse and watered at three to four day intervals. Forty-eight of the smallest plants were allocated to the flood experiment, while eighteen of the largest plants were allocated to the fire experiment. Plants were randomly allocated to levels of each treatment within the flood or fire experiments.

Flood experiment

The forty-eight *E. botryoides* seedlings allocated to the flood experiment were grown in an unheated glasshouse for two weeks before commencing the experiment.

At the start of the experiment, height, and the number of true leaves, budding leaves, and cotyledon leaves were counted. True leaves were defined as completely developed, green leaves, while budding leaves were defined as underdeveloped leaves distinguishable by their small size and presence of dark-red hairs dominating the leaf surface. Each seedling was randomly assigned to one of three treatment groups: control, waterlogged, or inundated (Fig. 1). Plants within the same treatment group were then allocated to randomly assigned pairs which were grown in 20 L clear plastic tubs. A tub containing two plants of the same treatment group was classed as a replicate, allowing eight replicates per treatment. The tubs containing control plants were well-drained, while the tubs containing waterlogged and inundated plants were watertight. The tubs used for the waterlogging treatment were filled with water to the soil level of the seedling pots, such that the roots were submerged but the stem and leaves were not (Fig. 1). The tubs used for the inundation treatment were filled with water until the plants were completely submerged (Fig. 1).

The tubs were positioned randomly in an unheated glasshouse. The plants were monitored two to three times weekly, during which time the control plants were watered and the water levels for the waterlogged and inundated plants were replenished if necessary.

At 2, 4, 6, and 8 weeks, mortality was recorded, as was the height and number of leaves of each living plant. Once measurements were completed, the tubs were moved to different random positions in the glasshouse to reduce the impacts of microclimate variation within the glasshouse. Seedling mortality and leaf-count data were graphed and analysed visually to determine response trends. Height data were converted to per cent change in height over each two-week interval. The height data were analysed using a two-way ANOVA in IBM SPSS version 24.

At the end of week 4, one plant from each replicate pair was randomly chosen to assess biomass. These plants were cleaned then dried at 80 °C for 72 hrs. The dry weight of each harvested plant was measured to provide total weight. The shoot of each plant was carefully separated from the roots and weighed to provide a shoot to root weight ratio. This process was repeated on the remaining plants at the end of week 8. Dead plants were excluded. A two-way ANOVA was performed to compare the difference in the mean total weight, and mean shoot to root weight ratio over time, within and between treatment groups.

Fire experiment

Eighteen *E. botryoides* seedlings were allocated to the fire experiment. Prior to burning, each seedling was measured for height, and the basal diameter recorded (in mm) using calipers. Each seedling was then randomly assigned to one of three treatment groups: unburnt control, low-intensity fire, or high-intensity fire. The intensity of each fire treatment was determined by fire fuel load. The low-intensity fire was created using 35 g of air-dried grass fuel, while the high intensity fire was created using 70 g of air-dried grass fuel.

Each 1 L pot containing a seedling was individually placed into a 26 cm diameter bucket.

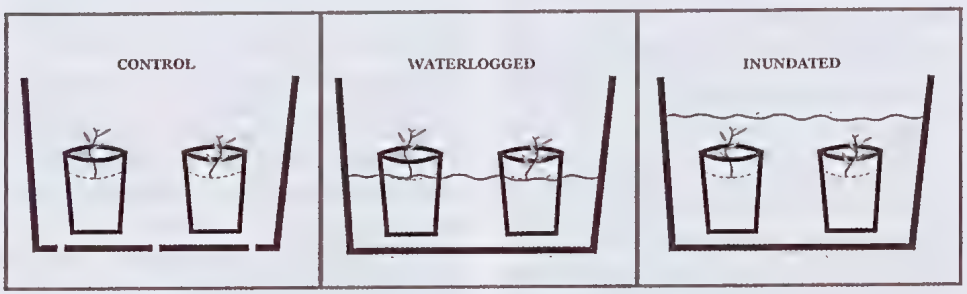

Fig. 1. Diagrammatic representation of each treatment. Randomly assigned pairs of plants from either the control, waterlogged or inundated group were grown in 20 L clear plastic tubs.

The bucket was filled with sand to protect the plastic pot and plant roots from fire. The pre-weighed grass fuel was then scattered across the top of the pot around the seedling, ensuring the stem and leaves were sitting above, rather than under the grass fuel. A cotton bud soaked in methylated spirits was then ignited and dropped into the centre of the bucket. For each burn, the time until the fire reached the edge of the bucket was recorded to calculate rate of spread (r), and the total duration of each fire was timed. The intensity (I) of each fire was calculated as $I = hwr$, where h is a constant for the heat yield of the grass litter (equal to 16000 kJ/kg), w is the weight of the fuel in kg per square metre, and r is the rate of spread in m/s. An independent-samples t-test was used to compare the mean fire intensity of the low and high fuel load fires.

All plants were watered thoroughly immediately after the treatment, and two to three times weekly thereafter. Plants were re-measured for their basal diameter, lignotuber diameter, height and any signs of visible recovery each week for four weeks.

Results

Flooding experiment

Seedlings were tolerant to waterlogging of their roots, and persisted for up to four weeks in inundated conditions before mortality increased (Fig. 2). By the end of the experiment, mortality of inundated plants was 75% whereas waterlogged plants had <15% mortality.

Flooding negatively impacted the growth of *E. botryoides* seedlings. This became more pronounced over time (Fig. 3). There was a significant main effect of treatment ($F_{(2,177)} = 2.952$, $p<0.05$), and a significant interaction effect between treatment and time ($F_{(8,177)} = 2.603$, $p<0.05$).

Flooding conditions had different effects on resource allocation patterns to roots and shoots. Control and waterlogged plants continuously allocated resources to both shoot and root growth, while inundated plants prioritised resource allocation to shoot growth (Fig. 4).

Leaf production and growth continued over time in the control group and, to a lesser extent, in the waterlogged group. Leaf abscission became increasingly common in the inundated plants (Fig. 5a) and bud production ceased by the end of the experiment (Fig. 5b).

Fire experiment

Low-intensity fire treatment (mean = 712 ± 101 Kw/m) significantly differed from high-intensity fire treatment (mean = 1157 ± 139 Kw/m) ($t = -2.585$, $p<0.05$). Only one plant resprouted after fire, from a low intensity-treatment (I = 571 kW/m). It had the largest basal diameter

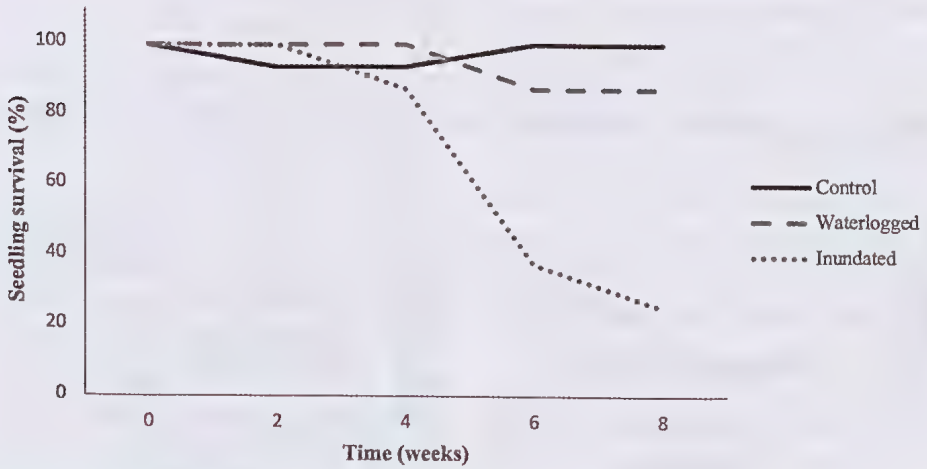

Fig. 2. Survival (%) of *Eucalyptus botryoides* seedlings over time (weeks) when subjected to varying degrees of flooding.

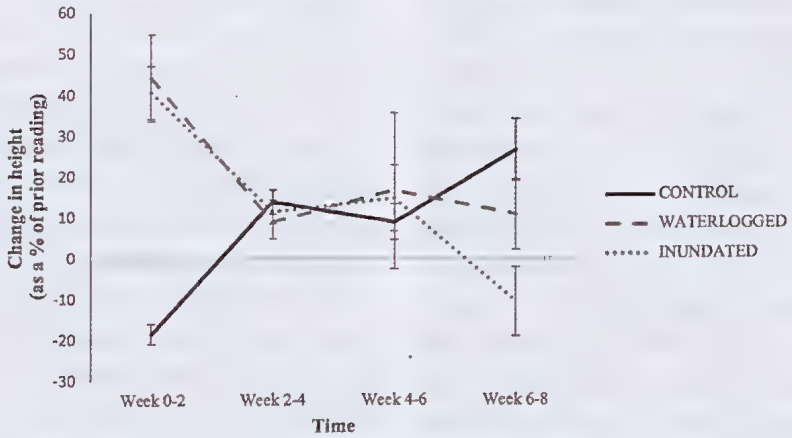

Fig. 3. The growth (change in height; % change from previous record) over time of control, waterlogged and inundated *E. botryoides* seedlings. Error bars represent standard error.

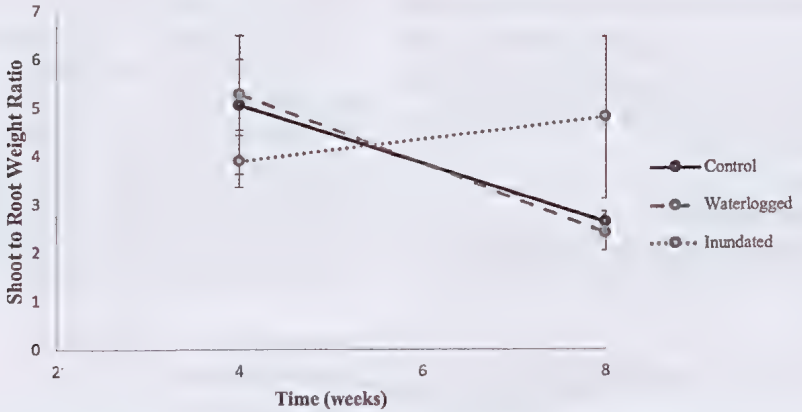

Fig. 4. Shoot to root weight ratio of seedlings after 4 and 8 weeks of different flooding treatments. Error bars represent standard error.

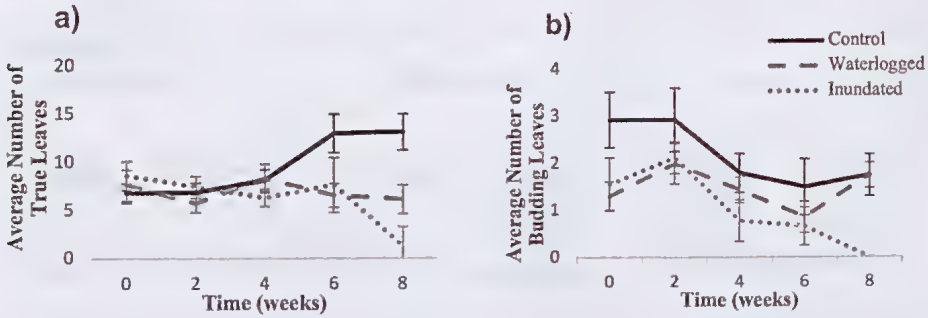

Fig. 5. a) The average number of true leaves per plant for each treatment; **b)** The average number of budding leaves per plant for each treatment. Error bars represent standard error.

(3.9 mm) of all plants in the low-intensity fire treatment group. All other burnt plants died.

Discussion

Scicluna *et al.* (2018) documented the encroachment of Southern Mahogany *E. botryoides* into a wet heathland at Cape Conran, and proposed that changes in hydrology (lack of waterlogging) and fire (the absence of frequent fire) were important drivers of this pattern. In the current study, these mechanisms were tested in a glasshouse experiment manipulating water and fire. Seedlings were found to be vulnerable to both fire and flooding. When completely submerged by water, seedling growth was inhibited and mortality was high. Survival and growth, surprisingly, were not adversely affected by partial waterlogging relative to control plants. When burnt in experimental fires, *E. botryoides* seedlings were essentially fire-intolerant, and only a single seedling survived.

Flooding can create anoxic conditions, presenting a major abiotic stress for many plant species (Bailey-Serres and Voesenek 2008). Adaptive responses to flooding have been observed across *Eucalyptus* in both adults and seedlings (Blake and Reid 1981; Argus *et al.* 2015; Greet 2015). This experiment showed that *E. botryoides* seedlings have a remarkable tolerance to waterlogging; only one waterlogged plant perished during the 8 weeks of this experiment. In addition to low mortality, waterlogged plants continuously allocated resources to new stem, root and leaf growth. Similar abilities have been recognised in *E. camphora* (Greet 2015) and *E. camaldulensis* (Argus *et al.* 2015). These studies made particular note of extensive adventitious root development and increased aerenchyma formation as mechanisms for tolerating waterlogging. These attributes were not considered in the current study, but may explain the resilience of waterlogged *E. botryoides* seedlings.

Inhibition of new growth and premature leaf abscission are common symptoms of woody plants stressed by flooding (Kozlowski 1997; Clemens and Pearson 1977), both of which were observed in completely inundated plants in this experiment. Under severe flooding conditions, gas exchange is drastically reduced (Bailey-Serres and Voesenek 2008). Surprisingly, even with reduced gas exchange, completely inundated plants continued to grow. The observed increase in height was possibly due to specialised resource allocation. Over time, the shoot to root weight ratio in inundated plants increased, indicating that resources were allocated to stem elongation. This response has been recognised in plants as the 'low-oxygen escape syndrome', whereby carbon is allocated to rapid elongation of shoot organs to facilitate escape from flooding stress (Bailey-Serres and Voesenek 2008). *Eucalyptus botryoides* seedlings were not allowed to emerge from the surface of the water during this experiment, so were unable to re-establish gas exchange necessary for survival. As the reserves of seedlings were exhausted, mortality increased. For *E. botryoides* seedlings mostly <10 cm tall, reserves generally sustained the plants for up to four weeks before seedlings died.

The ability of seedlings to recover from temporary waterlogging and inundation would be a valuable dynamic to better understand, particularly in systems where *E. botryoides* is encroaching or extending beyond its indigenous range. This dynamic has been explored in *Eucalyptus marginata* seedlings, revealing that the probability of post-flood seedling recovery decreases as the duration of flooding increases (Davison and Tay 1985). A study focusing on post-flooding root recovery in *E. camaldulensis* seedlings found that root biomass failed to be restored once seedlings were removed from flooded conditions (Argus *et al.* 2015).

Other considerations may include local adaptations. Flooding tolerance of plant species can vary greatly between populations due to genetic and/or environmental differences. While *E. botryoides* commonly occurs on sandy soils and may typically show poor tolerance to waterlogging, the plants for this experiment were sourced from clay soils. The local adaptations of these plants may contribute to the surprising tolerance of *E. botryoides* seedlings observed in this experiment.

Eucalyptus botryoides seedlings were very susceptible to fire. Seedlings used in this experiment had a well-developed lignotuber but only one seedling resprouted from its lignotuber after fire, indicating that lignotuber function at this early stage of plant development is not reliable. The resprouting individual had a relatively

large basal diameter (3.9 mm) and experienced an especially low intensity fire (~570kW/m), providing further support of fire-sensitivity in seedlings at this stage of development (<30 cm).

The distribution of *E. botryoides* is commonly associated with temperate coastal heathlands (Benson and McDougall 1998). In most temperate heathlands, fire intensities range from 100 kW/m to 77 000 kW/m (Cruz *et al.* 2015). Due to the dense foliage cover and highly flammable properties of coastal heathland species (Cruz *et al.* 2015), fire intensity is typically high (Cheal 2010). Therefore, the wildfires experienced by *E. botryoides* in its indigenous range are probably too great in intensity for small (<30 cm) seedlings to survive.

As predicted by Scicluna *et al.* (2018), the absence of fire likely favours *E. botryoides* recruitment in these systems. Fire is an integral process within heathlands (Enright *et al.* 2012), and *E. botryoides* encroachment into coastal heathland is one example of how community structure and composition can change over time when fire regimes are altered (Bennett 1994; Lunt 1998; Scicluna *et al.* 2018). Since coastal heathlands typically experience high frequency and high intensity fires (Cheal 2010), the impacts of repeated burns on more mature *E. botryoides* plants would be key to understanding the processes that can facilitate or prevent encroachment. Once these dynamics are better understood, prescribed burning may be an effective management tool to prevent (or encourage) *E. botryoides* encroachment, as desired.

Expanding our knowledge of how fire and flood interact to influence the success of *E. botryoides* would be highly relevant. The coastal wet heathlands with which *E. botryoides* is associated experience these two abiotic processes in concert. During the dry season, plants previously stressed by flooding may show reduced capacity to survive even low-intensity fires. Likewise, during the wet season, if plants have previously resprouted from lignotubers, their height loss will make them far more vulnerable to flooding as they are more likely to experience complete inundation rather than waterlogging of their roots only.

Climate change is expected to cause further drought and increased fire frequency in temperate heathlands (Enright 2012). The fire-flood dynamic described above will be altered by these changes. An increase in fire frequency is likely to be detrimental to *E. botryoides* recruitment. By contrast, reduced rainfall and therefore altered flooding regimes may favour *E. botryoides* recruitment. Even during drought conditions, the soils of wet heathlands probably have a higher moisture content than those of the surrounding habitat, but without creating anoxic conditions. As a result, these times of drought may make wet heathland soils even more favourable for *E. botryoides* recruitment than the surrounding habitat.

Conclusion

Eucalyptus botryoides seedling survival is reduced by inundation and fires of relatively low intensity. Encroachment into coastal wet heathland is therefore likely to be facilitated in the absence of fire and during relatively dry periods. Restoration of appropriate fire and flooding regimes may help to recover the coastal wet heathland invaded by *E. botryoides* at Cape Conran, but future climate change is likely to interrupt these important ecological processes. The responses of *E. botryoides* to future changes in flood-fire dynamics will be highly relevant to coastal wet heathland recovery and persistence.

Acknowledgements

This research was undertaken as part of an undergraduate research project at La Trobe University. I would like to thank Dr John Morgan for supervising this study, and for his encouragement to publish the research, and edits to the final paper. I thank the La Trobe University Wildlife Sanctuary for providing me with a source of seedlings, and Zac Walker and Nick Moore for their assistance in the setting up and maintenance of this experiment.

References

Alofs KM and Fowler NL (2013) Loss of native herbaceous species due to woody plant encroachment facilitates the establishment of an invasive grass. *Ecology* **94**, 751–760.

Archer SR, Andersen EM, Predick KI, Schwinning S, Steidl RJ and Woods SR (2017). Woody Plant Encroachment: Causes and Consequences. In *Rangeland Systems*, pp. 25–84. Ed DD Briske. (Springer International Publishing: Cham).

Argus RE, Colmer TD and Grierson PF (2015) Early physiological flood tolerance is followed by slow post-flooding root recovery in the dryland riparian tree *Eucalyptus camaldulensis* subsp. *refulgens*. *Plant, Cell & Environment* **38**, 1189–1199.

Asner GP, Elmore AJ, Olander LP, Martin RE and Harris AT (2004) Grazing systems, ecosystem responses, and global change. *Annual Review of Environmental Resources* **29**, 261–299.

Bailey-Serres J and Voeseneck LACJ (2008) Flooding Stress: Acclimations and Genetic Diversity. *Annual Review of Plant Biology* **59**, 313–339.

Bennett LT (1994) The expansion of *Leptospermum laevigatum* on the Yanakie Isthmus, Wilsons Promontory, under changes in the burning and grazing regimes. *Australian Journal of Botany* **42**, 555–564.

Benson D and McDougall L (1998) Part 6, Dicotyledon family Myrtaceae. In *Ecology of Sydney plant species*, pp. 871–872. Ed D Benson and L McDougall. (National Herbarium of New South Wales, Royal Botanic Gardens: Sydney)

Blake T and Reid D (1981) Ethylene, water relations and tolerance to waterlogging of three *Eucalyptus* species. *Australian Journal of Plant Physiology* **8**, 497.

Bowman DMJS (2000) *Australian Rainforests: Islands of Green in a Land of Fire.* (Cambridge University Press. : Cambridge)

Brook BW and Bowman DMJS (2006) Postcards from the past: charting the landscape-scale conversion of tropical Australian savanna to closed forest during the 20th century. *Landscape Ecology* **21**, 1253–266.

Burrell JP (1981) Invasion of coastal heaths of Victoria by *Leptospermum laevigatum* (J. Gaertn) F. Muell. *Australian Journal of Botany* **29**, 747–764.

Cheal D (2010) Growth stages and tolerable fire intervals for Victoria's native vegetation data sets. Fire Adaptive Management Report No. 84. Victorian Government Department of Sustainability and Environment.

Clemens J and Pearson CJ (1977) The effect of waterlogging on the growth and ethylene content of *Eucalyptus robusta*. *Oecologia* **29**, 249–255.

Costello DA, Lunt ID and Williams JE (2000) Effects of invasion by the indigenous shrub *Acacia sophorae* on plant composition of coastal grasslands in south-eastern Australia. *Biological Conservation* **96**, 113–121.

Costermans LF (2006) *Trees of Victoria and Adjoining Areas.* (Costermans Publishing: Frankston)

Cruz MG, Gould JS, Alexander ME, Sullivan AL, McCaw WL and Matthews S (2015) *A Guide to Rate of Fire Spread Models for Australian Vegetation.* (CSIRO Land and Water: Canberra)

Davison EM and Tay FCS (1985) The effect of waterlogging on seedlings of *Eucalyptus marginata*. *New Phytologist* **101**, 743–753.

Enright NJ, Keith DA, Clarke MF and Miller BP (2012) Fire regimes in Australian sclerophyllous shrubby ecosystems: heathlands, heathy woodlands and mallee woodlands. In *Flammable Australia: Fire Regimes, Biodiversity and Ecosystems in a Changing World*, pp. 215–234. Eds RJ Williams, RA Bradstock and AM Gill. (CSIRO Publishing: Collingwood)

Freestone M, Wills TJ and Read J (2015) Post-fire succession during the long-term absence of fire in coastal heathland and a test of the chronosequence survey method. *Australian Journal of Botany* **63**, 572–580.

Grant CD, Koch JM, Bell DT and Loneragan WA (1997) Tree species response to prescribed burns in rehabilitated bauxite mines in Western Australia. *Australian Forestry* **60**, 84–89.

Greet J (2015) The marked flooding tolerance of seedlings of a threatened swamp gum: implications for the restoration of critical wetland forests. *Australian Journal of Botany* **63**, 669–678.

Hazard J and Parsons RF (1977) Size-class analysis of coastal scrub and woodland, Western Port, southern Australia. *Australian Journal of Ecology* **2**,187–197.

Higgins SI, Bond WJ, and Trollope WS W (2000) Fire, resprouting and variability: a recipe for grass-tree coexistence in savanna. *Journal of Ecology* **88**, 213–229.

Kozlowski TT (1997) Responses of woody plants to flooding and salinity. *Tree Physiology Monograph* **1**, 1–29.

Lacey CJ (1983) Development of large plate-like lignotubers in *Eucalyptus botryoides* Sm. in relation to environmental factors. *Australian Journal of Botany* **31**, 105–118.

Lacey CJ, Gillison AN and Whitecross MI (1982) Root formation by stems of *Eucalyptus botryoides* Sm. in natural stands. *Australian Journal of Botany* **30**, 147–159.

Lunt ID (1998) *Allocasuarina* (Casuarinaceae) invasion of an unburnt coastal woodland at Ocean Grove, Victoria: structural changes 1971–1996. *Australian Journal of Botany* **46**, 649–656.

Lunt ID, Winsemius LM, McDonald SP, Morgan JW and Dehaan RL (2010) How widespread is woody plant encroachment in temperate Australia? Changes in woody vegetation cover in lowland woodland and coastal ecosystems in Victoria from 1989 to 2005. *Journal of Biogeography* **37**, 722–732.

Morgan J, Wright J, Whelan J, Clarke M, Coulsen G, Lunt I, Stoner J, Varcoe and T Shannon J (2018) What does it take to do successful adaptive management? A case study highlighting Coastal Grassy Woodland restoration at Yanakie Isthmus. *Ecological Management and Restoration* **19**, 111–123.

O'Loughlin LS, Green PT, and Morgan JW (2015) The rise and fall of *Leptospermum laevigatum*: plant community change associated with the invasion and senescence of a range-expanding native species. *Applied Vegetation Science* **18**, 323–331.

Price JN and Morgan JW (2008) Woody plant encroachment reduces species richness of herb-rich woodlands in southern Australia. *Austral Ecology* **33**, 278–289.

Schlesinger WH, Reynolds JF, Cunningham GL, Huenneke LF, Jarrell WM, Virginia RA, and Whitford WG (1990) Biological feedbacks in global desertification. *Science* **247**, 1043–1048.

Scholes RJ and Archer SR (1997) Tree grass interactions in savannas. *Annual Review of Ecology and Systematics* **28**, 51–544.

Scicluna EL, Makdissi R, Gribble MJ, Loukes BT, Hernandez OF and Morgan JW (2018) Recent encroachment on a Wet Heathland by eucalypts at Cape Conran, Victoria. *The Victorian Naturalist* **135**, 4–9.

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Further trapping records of the Little Pied Bat *Chalinolobus picatus* in Yarrara Fauna and Flora Reserve, Victoria

Fauna Survey Group Contribution No. 31

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Abstract
The Little Pied Bat *Chalinolobus picatus* was caught in Victoria for the first time during a survey of vertebrate fauna in the Yarrara and Mallanbool Flora and Fauna Reserves undertaken in spring 2014. An additional survey undertaken by the Fauna Survey Group of the Field Naturalists Club of Victoria, while harp trapping in Yarrara Flora and Fauna Reserve in the spring of 2018, resulted in a further nine detections, including the first male caught in the state. (*The Victorian Naturalist* **136** (4), 2019, 150–152)

Keywords: Little Pied Bat, *Chalinolobus picatus*, further records, Victoria, Yarrara Flora and Fauna Reserve

Introduction

The Little Pied Bat *Chalinolobus picatus* was first confirmed to occur in Victoria during a survey for vertebrate fauna undertaken at Yarrara and Mallanbool Flora and Fauna Reserves (FFR) in spring 2014 (Drury and Antos 2016; Bewsher *et al.* 2019). Yarrara FFR is located approximately 70 km west of Mildura in the Murray Mallee region of Victoria.

The Fauna Survey Group returned to Yarrara FFR in late September 2018 with the aim of adding to vertebrate fauna records for the area. It was hoped that the group might be successful in trapping the Little Pied Bat again.

Methods

Harp trapping took place in Yarrara FFR on five nights from 23–27 September 2018. The first and fifth nights were at, or within, approximately 130 m of the original site where four Little Pied Bats were caught in 2014 in Yarrara Area 2 (centre-south block; 34° 24' S, 141° 24' E). Traps were set in the old irrigation channel and amongst nearby Belah *Casuarina pauper* and Slender Cypress-pines *Callitris gracilis* subsp. *murrayensis* with fissures and hollows that might provide roost sites. The third night saw traps erected in the channel 500–900 m further to the south-west of this site. On the second night harp traps were set in different sections of the channel located in mallee approximately 3.1 km to the south-east, while on the remaining (fourth) night they were put up in Belah woodland about 1.2 km to the south-east of where the Little Pied Bats were caught. Coordinates for the trap locations are shown in Table 1.

Four traps were set each evening, and all were left up overnight, totalling 20 trap nights. They were checked at approximately 2200 hrs each evening and at about 0700 hrs on the following morning. Specific methods relating to trap setup, including trap type and height, and procedures for bat handling and processing, followed Bewsher *et al.* (2019).

Results

The weather was generally cooler and less windy than in 2014. Daily temperatures at Lake Victoria (approximately 42 km north of the study area) ranged between minimums of 4–11.5 °C and maximums of 20–26.2 °C (Bureau of Meteorology 2018). Four days prior to the start of the survey, 4.4 mm of rain was recorded in the area (at Werrimull) (Bureau of Meteorology 2018), although the ground was dry by the time the survey began.

On the first night, four female Little Pied Bats were captured at the site where they were first found in 2014. We then caught five Little Pied Bats on the fifth night of trapping at, or within, 130 m of the same site. One male was caught (the only male caught during both surveys) (Fig. 1), one female was observed to

be lactating and another one was gravid. The morphometric details, sex and reproductive status of each individual are shown in Table 2.

A summary of all bats caught during the survey is shown in Table 3.

Discussion

The fifth night of trapping extended the trap records in Yarrara by approximately 130 m to the south-west of the original site where the Little Pied Bat was caught in 2014. As no bats were marked, it is not known whether some of the females trapped on the last night were recaptures.

Given that all of the Little Pied Bats caught on this occasion were in the same vicinity as those captured in 2014, it is apparent that the species is resident in Yarrara FFR. This is supported by the presence of lactating and pregnant females found on each occasion, suggesting there is likely to be a maternity colony near the trapping site. It is interesting that the species has been recorded only in the north-west section of the reserve and not at any of the other trap sites

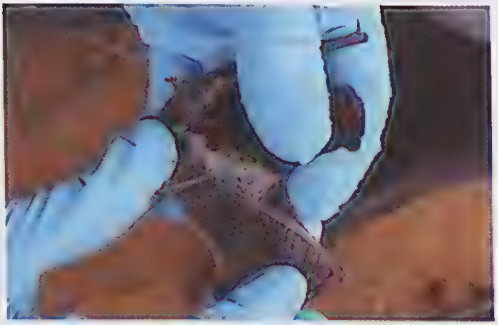

Fig. 1. Underside of the male Little Pied Bat caught at Yarrara Flora and Fauna Reserve in September 2018. Photo Andrej Hohmann.

Table 1. Locations where traps were set in Yarrara FFR.

Area within Yarrara FFR	Date	Trap number	Latitude (S)	Longitude (E)
1 (north-west block)	23 September 2018	1	34° 23' 26.3"	141° 23' 7.5"
		2	34° 23' 26.3"	141° 23' 8.1"
		3	34° 23' 26.8"	141° 23' 9.1"
		4	34° 23' 26.6"	141° 23' 10.5"
	27 September 2018	1	34° 23' 27.9"	141° 23' 2.3"
		2	34° 23' 26.7"	141° 23' 5.2"
		3	34° 23' 27.0"	141° 23' 7.5"
		4	34° 23' 26.3"	141° 23' 7.5"
2 (centre-south block)	24 September 2018	1	34° 24' 45.9"	141° 24' 25.2"
		2	34° 24' 44.1"	141° 24' 25.9"
		3	34° 24' 42.7"	141° 24' 29.4"
		4	34° 24' 39.8"	141° 22' 35.9"
3 (north-west block)	25 September 2018	1	34° 23' 39.3"	141° 22' 52.9"
		2	34° 23' 43.2"	141° 22' 46.1"
		3	34° 23' 40.5"	141° 22' 37.7"
		4	34° 23' 43.2"	141° 22' 40.1"
4 (centre-north block)	26 September 2018	1	34° 23' 44.7"	141° 23' 51.5"
		2	34° 23' 45.3"	141° 23' 52.3"
		3	34° 23' 46.2"	141° 23' 55.6"
		4	34° 23' 46.1"	141° 23' 56.2"

Table 2. Morphometric and other data obtained for Little Pied Bats *C. picatus* trapped.

Individual	Date caught	Sex	Weight (g)	Forearm length (mm)	Reproductive condition
1	23 September 2018	Female	6.9	35.4	
2	23 September 2018	Female	6.6	35.1	
3	03 September 2018	Female	6.5	36.6	
4	23 September 2018	Female	7.2	35.9	
5	27 September 2018	Female	7.5	36.0	Lactating
6	27 September 2018	Male	5.2	34.2	
7	27 September 2018	Female	6.4	36.4	
8	27 September 2018	Female	7.1	35.2	
9	27 September 2018	Female	7.1	36.1	Pregnant

Table 3. Bat results for each area surveyed.

	Survey area				
	Yarrara Area 1	Yarrara Area 2	Yarrara Area 3	Yarrara Area 4	Total
Date traps set	23 Sept. 2018/ 27 Sept. 2018	24 Sept. 2018	25 Sept. 2018	26 Sept. 2018	
No. of trap nights	8	4	4	4	20
Species					
Gould's Wattled Bat *Chalinolobus gouldii*	1				1
Chocolate Wattled Bat *Chalinolobus morio*	2				2
Little Pied Bat *Chalinolobus picatus*	9				9
Lesser Long-eared Bat *Nyctophilus geoffroyi*	3		4	9	16
Forest Bats *Vespadelus spp.*	4		2		6
White-striped Freetail Bat *Austronomus australis*	*1				*1
Freetail Bat *Mormopterus* sp.				1	1
Total detections	20	0	6	10	36

**Austronomus australis* was heard rather than captured.

in the central or southern sections of Yarrara FFR (n = 3 additional sites in 2014 and 2018 respectively). It is not known why this is the case, although all of the traps which caught Little Pied Bats during both surveys were set in the channel and were adjacent to Belah and Slender Cypress-pine that contained hollows. However, trees supporting hollows were also present near several of the other trap sites.

The capture of the single male is significant, as it is the first male Little Pied Bat to be trapped in Victoria.

The capture of Little Pied Bats for a second time in the same location at Yarrara FFR and at none of the other sites where traps were set up in 2014 and 2018, reinforces the need for more surveying (trapping and acoustic recording) in other parts of the reserve, as well as in surrounding public and private land which could potentially provide habitat for the species. Marking individuals (e.g. using Passive Integrated Transponder or 'PIT' tags) would also enable the identification of recaptures and a more reliable assessment of the local population size. Tracking the bats or closer study of the nearby vegetation may also assist in locating potential roost sites.

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References

Bewsher S, De Angelis D and Hansen K (2019) The Little Pied Bat *Chalinolobus picatus*: a confirmed addition to the mammal fauna of Victoria. *The Victorian Naturalist* **136**, 70–77.

Bureau of Meteorology (2018) Climate Data Online. Australian Bureau of Meteorology, Melbourne. <http://www.bom.gov.au/climate/data/>. Accessed 28 October 2018.

Drury R and Antos M (2016) A fauna survey in Yarrara Flora and Fauna Reserve and adjacent reserves in north-western Victoria: Fauna Survey Group Contribution No. 27. *The Victorian Naturalist* **133**, 10–20.

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The secret world of the Net-casting Spider *Deinopis subrufa*

One morning in early February 2019, I noticed a Net-casting Spider *Deinopis subrufa* resting on the wall near the back door of my Templestowe home. I had probably inadvertently disturbed it as these spiders, although reasonably common across Australia, are seldom observed during the day. They hide motionless in vegetation, facing downwards with their long, thin front and back legs held together in pairs, giving them a stick or cross-like appearance (Fig. 1). I was able to identify the species as I had seen it two or three times before. Checking Mascord (1993), I confirmed it was a female. The spider's speckled, fawn-coloured body was about 2 cm in length with two matching tubercles on each side of her abdomen. Her underside was light orange, divided by a longitudinal grey stripe.

Deinopis subrufa has eight eyes, two of which are enormously enlarged and face forward, very much like vehicle headlights. They dominate the face, hence its common name Ogre-faced Spider. Two much smaller eyes are located on each side of the head, with two more below the huge eyes. Another set is almost buried in a pair of hairy knobs on each side of the face (Whyte and Anderson 2017) (Fig. 2). The genus name *Deinopis* is derived from the Greek *deinos* meaning 'fearful', and *opis* meaning 'appearance'.

The Net-casting Spider's method of hunting is unique in the spider world. After dark it builds a scaffolding of fine, transparent silk and suspends itself directly above a place where prey is likely to pass. This is often close to the ground. Head up, it constructs a 1.5–2.0 cm rectangular net of thick, fuzzy, bluish-white silk. The spider then turns and, facing down, stretches the net loosely between the tips of its front pairs of legs. There it waits patiently, its enormous, super-sensitive eyes alert for movement. It preys on small invertebrates such as mosquitoes, moths, beetles and ants. When a suitable creature comes within reach, the spider lunges forward and downwards and, with lighting speed, throws its net over the unsuspecting victim. The clinging, elastic silk envelops and entangles the prey, which is then bitten, para-

Fig. 1. *Deinopis subrufa*. (The web is incidental and belongs to a Black House Spider)

Fig. 2. *Deinopis subrufa*'s huge eyes partially ringed with red hairs.

lysed, wrapped in silk and eaten. Once the net has been used, the spider must construct another to continue hunting. Before daylight, an unused net is usually eaten by the spider (Gray 2019; McKeown 1952).

After recognising *D. subrufa*, I observed her carefully, noting that she settled for the day in scrubby vegetation near the garden tap. I waited impatiently for darkness to fall. Would she make a net? In the evening I kept popping in and out of the back door until, at about 10 pm, I was rewarded by seeing her holding a beautiful, light-blue, crinkled net. The whole thing looked to me like a skein of knitting wool stretched out waiting to be rolled into a ball (Fig. 3). Although I watched hopefully for a long time, I did not see the net thrown.

The Net-casting Spider's extraordinary hunting device is made of cribellate silk. The cribellum is a special organ, found on the underside of the spider's abdomen near its spinnerets (Whyte and Anderson 2017). From here, blue-white silk with a sticky, woolly texture is combed out (Fig. 4). Clyne (1977, p. 83) explains: 'The cribellate silk is placed as a thick, jelly-like overlay on two strands of ordinary silk from the spinnerets.'

The fascinating little creature stayed around for nearly two weeks. By day she hid in the same patch of foliage. During this period I was able to take many photographs and find out more about her life. I read that, in order to create a target, Net-casting Spiders drop splashes of white faecal material onto the substrate directly under their nets (Gray 2019). Sure enough, I found tiny, white 'bullseyes' on the concrete below the ambush site (Fig. 5). It was truly extraordinary learning about the spider's eyes. *Deinopus subrufa*'s enormous eyes are used only at night. Each dawn they digest the light-sensitive retina, and each evening it is regrown (Whyte and Anderson 2017). I cannot help wondering how this was discovered.

Fig. 3. *Deinopis subrufa* poised to ambush prey.

Fig. 4. Cribellate silk.

One evening I decided to try to video the spider constructing its net, so I set up lights and kept her under observation from 9.30 pm onwards. She had already built a framework of guy lines and stablising threads and was resting facing down. About an hour later I saw

her turn, position herself head up and swing her abdomen rapidly from side to side, combing out cribellate silk with specialised bristles on the tips of her back legs. Unfortunately, she was disturbed by my attention and ceased to build her net, so, having taken a few still images (e.g. Fig. 6), I left her in peace.

Early in the morning of 16 February I went out first thing, as was my habit, to locate the spider. She was nowhere to be found, but, to my great surprise and delight, she had left behind a tiny, blue net (Fig. 7). The exquisite, postage stamp-sized net was held up by support lines of thin silk. An unused net is sometimes left in place for the next night's hunting. I photographed it and went to have breakfast. Unfortunately, when I returned, the little net had gone. I suspect a pair of Common Blackbirds *Turdus merula,* that were fossicking nearby, had pecked at it.

The next day I saw the spider again. Her behaviour had changed. Instead of remaining well camouflaged, she was moving from place to place in daylight. She ran behind a box of gardening equipment and the image I took then turned out to be my last. Although I continued to search during the next few nights and days, she had disappeared, possibly to look for a better hunting spot or a place to moult, or perhaps to seek a mate.

I did not ever see this spider catch prey, but, nine years ago, I was lucky to see a similar spider fling its net over a mosquito in my sister's garden. A phone call came late one night and I grabbed my camera and drove over. The little spider had set up its net in a patch of ivy. As I watched, I suddenly realised the net had been thrown. It was all over in an instant, far too rapidly for me to photograph. But I did take a poor image of the insect caught in a ragged, unfolded net.

I recently received a link to a YouTube video that must surely be the holy grail of spider photography. Both the building of a net and the capture of prey are shown in minute detail. The YouTube video is titled 'The Net Casting Spider *Deinopis cornigera*'. That name refers to the Short-palp Ogre-faced Spider, which is found in Africa, but at the beginning of the commentary, it is said to have been filmed in Australia (iNaturalist).[1]

Fig. 5. Splashes of white faecal matter beneath the net. The number and position of spots indicates that the net was built in a slightly different place each night.

Fig. 6. *Deinopis subrufa* facing head up, constructing a net.

What of the male Net-casting Spider? I once observed the smaller male in my garden, but beyond identifying it and checking to see whether it had made a net, I did not watch it closely. A fellow naturalist photographed a male in March this year (Fig. 8) and has kindly allowed me to use her image. I found that this was a male *D. subrufa* after its final moult when his body shape alters. The legs extend, the abdomen thins and he ceases hunting (Clyne 1977). His sole aim is to mate.

There is more to describe about the lives of Net-casting Spiders, but, as yet, I have not witnessed it. However, Clyne (1977) gives an excellent account of their complex mating behaviour.

To conclude, even in urban areas nature provides us with some intriguing creatures. There is no need to rely solely on Sir David Attenborough; just prowl around likely areas of your garden (with a torch at night), and discover them for yourselves. The secret world of spiders may be just outside your back door, as it was outside mine.

[1] iNaturalist is an online social network developed for mapping and sharing observations of biodiversity across the globe.

Acknowledgement
Thank you to Linda Rogan for the photo of a male *Deinopis subrufa* following its final moult (Fig. 8).

References

Clyne D (1977) *A Guide to Australian Spiders: Their Collection and Identification.* (Nelson: Melbourne).
Gray M (2019) Rufous Net-casting Spider: animal factsheet <http://www.australianmuseum.net.au> Accessed 20 May 2019.
iNaturalist (2019) *Deinopis cornigera* <https://www.inaturalist.org/observations?place_id=any&taxon_ id=490633> Accessed 20 May 2019.
McKeown KC (1952) *Australian Spiders: Their Lives and Habits.* (Angus and Robertson: Sydney).
Mascord R (1993) *Australian Spiders in colour.* (Reed: Sydney).
Whyte R and Anderson G (2017) *A field guide to spiders of Australia.* (CSIRO Publishing: Clayton South).
YouTube The Net Casting Spider, *Deinopis cornigera* <https://www.youtube.com/watch?v=5OfQkImeyMY>.

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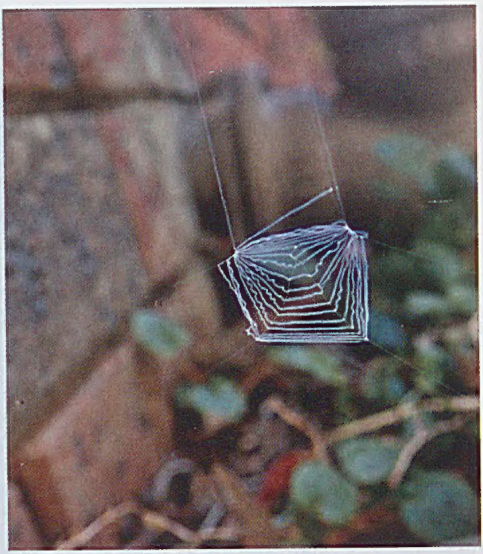

Fig. 7. Net found intact in the morning.

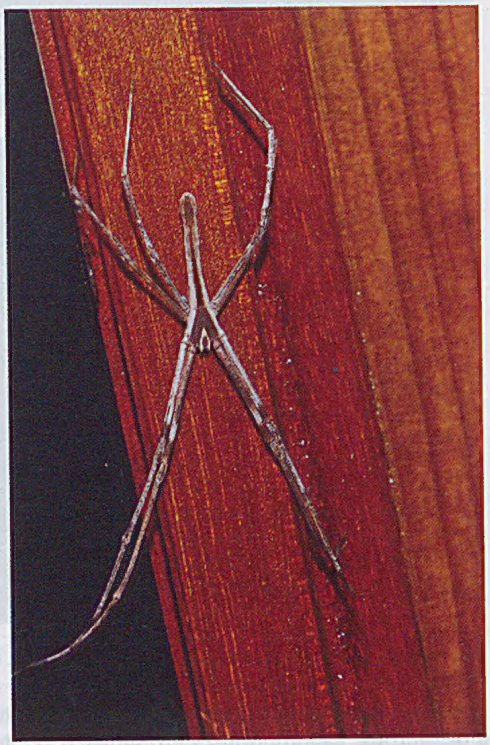

Fig. 8. *Deinopis subrufa* male following its final moult. Photo Linda Rogan.